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COLLABORATIVE DESIGN TECHNOLOGY: TOOLS AND TECHNIQUES FOR IMPROVING COLLABORATIVE DESIGN (U)

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FOR THE COMMANDER

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This report provides a composite review of the programmatical perspective, theoretical background, research foundations / methods, and 'situated' practice associated with the Collaborative Design Technological Laboratory (CDTL). Collaborative Design Technology denotes a triadic relationship among collaboration (interactive group process), design (a constructive task), and information technology. Selected issues in collaborative design and collaborative technology are given with the intent to leverage design technology. Reviews of background literature in computer-supported collaborative work and design rationale set the stage for the scope of enquiry into CDT. An analysis of the CDTL infrastructure and physical factors in ground support are discussed. The report provides a comprehensive depiction of all research activities including experimental, observational, simulation, and technology studies conducted by CDTL personnel. Examples of developing technology / projected guidelines are offered for group interfaces, desktop video conferencing, and the World Wide Web. Conclusions are drawn which highlight (1) the value (and the difficulty) of developing ecologically valid research paradigms and conducting ethnographic studies within collaborative design (2) the relative merit of collaborative technologies based on unit cost, compatibility, interoperability, commitment, and the social / behavioral changes necessary to implement systems (3) the difficulty of merely translating individual performance to group performance metrics.

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PREFACE

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INTRODUCTION

This report summarizes the work of the *Collaborative Design Technology Laboratory (CDT Lab)* -- a component of the Design Technology Branch, Armstrong Laboratory Human Engineering Division (AL/CFHD), at Wright-Patterson Air Force Base (WPAFB) in Dayton, Ohio. Earlier work under the project name AKADAM (Advanced Knowledge and Design Acquisition Methodology) had concentrated on IT-supported knowledge elicitation in the service of systems design, organizational re-design, and total quality management (cf. McNeese *et al*, in press). The CDT Lab was established as a follow-on extension of the AKADAM work (and primary AKADAM researchers) aimed at addressing collaboration in design and its facilitation through information technology. This report will summarize the work of the *Collaborative Design Technology Team (CDTeam)* during the period 1993-1995.

The CDT Lab was a component of AL/CFHD work aimed at realizing *Computer Aided Systems Human Engineering (CASHE)*, as described in Boff *et al.* (1991). Broadly speaking the CASHE "vision" entailed bringing advanced *information technology (IT)* to bear on the task domain of human factors engineering in systems of potentially large scale and complexity, as illustrated in Figure 1. The general goal was to promote ergonomics / human factors as a "full partner" among the participants in systems design. The more specific goal was to develop and deploy tools supporting human factors professionals in a manner analogous to the way CAD systems support structural engineers or CASE tools support software programmers.

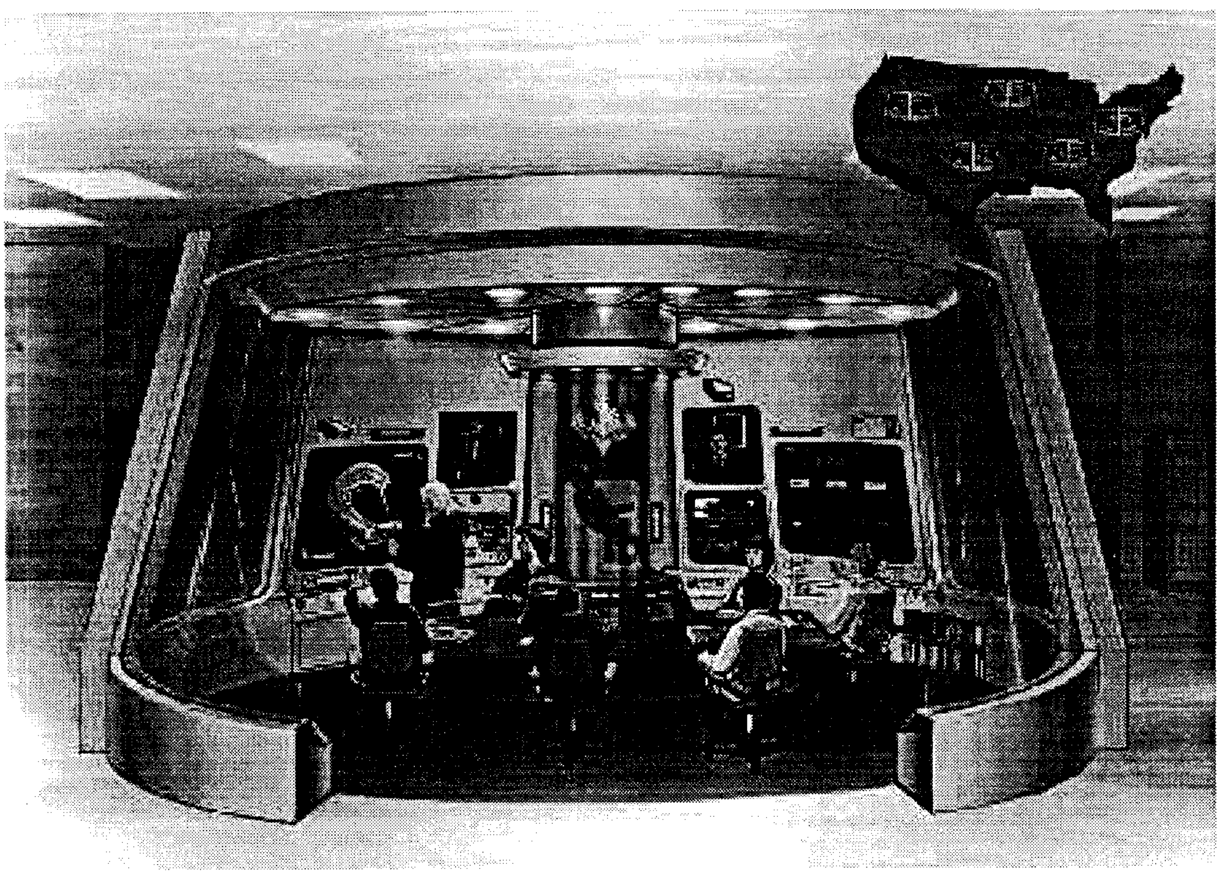

Figure 1: The CASHEVision

Figure 1 shows a multidisciplinary design team working with a CAD/CAE system and various design support tools to assess human performance implications of design decisions. The

combination of integrated visual, audio, and virtual reality display technologies promotes immediacy and fidelity in portraying outcomes of crew system design decisions, even during early conceptualization. All participants (e.g., program managers, engineers, end users), can see how the potential design changes will affect (e.g.) product form, potential functionality, project scheduling, budget criteria, etc. By linking the illustrated meeting scenario to other such sites, team members can readily and reliably communicate design concerns, proposals, and solutions to others throughout a distributed network. These capacities are of particular relevance to U.S. Air Force systems design and acquisition efforts, which typically involve hundreds of organizations and thousands of people distributed across North America.

The Collaborative Design Technology Laboratory (CDT Lab) was established in summer 1993 as AL/CFH's work unit dedicated to research and development in the area of applying information technology (IT) in support of design teams. The CDT Lab's mission as specified for the Logicon Technical Services Inc. support contract to AL/CFH is "... to apply a user-centered approach to the development of collaborative design technologies. Through the study of multidisciplinary design teams, the evolving collaborative technologies can be made to reflect the needs, capabilities, and limitations of the users." More concretely, the laboratory's mission was defined by Human Engineering Division management in August 1993 as: "... (to) enable and facilitate distributed group decision making, problem solving, and 'concept visualization' for simultaneous engineering and design."

The CDT Lab has pursued its mission by exploring the applicability of group support technologies to USAF design / acquisition. This focus has been motivated largely by the fact that design / acquisition accounts for the majority of all cost burdens (time, money, and human resources) necessary to deploy complex systems (e.g., aircraft) in support of USAF missions. This focus is further justified by CDT Lab's location at WPAFB -- the primary site for the Air Force Materiel Command, the Aeronautical Systems Center, and the System Project Offices (SPO's) overseeing USAF design/acquisition for major systems. The June 1994 *DOD Detailed Technology Area Plan (DTAP) on Human Systems Interface* details the goal of its Distributed Collaboration Technology Effort (which includes the CDT Lab) as being "...to develop methods to reduce collaborative planning time by 25 percent and collaborative execution time by 10 percent." By pursuing the DTAP goals with respect to the area of highest USAF cost burden in system deployment (design/acquisition), the CDT Lab has aimed to translate these percentage targets into maximum budgetary savings.

The focal points for such work are evident in Figure 1 -- a computer-supported co-located meeting linked via teleconferencing to remote partners. The specific human engineering orientation to systems design, coupled with the situation of CDT Lab within a major human factors organization, resulted in CDT Lab's common involvement in human factors aspects of design efforts. However, the issues and experiences deriving from these human engineering efforts have an applicability beyond the specific field of human factors. Large-scale systems design is today accomplished by multidisciplinary design teams drawn from a variety of backgrounds and organizations. Examples of other (not exclusively human factors) target scenarios involved in large systems design and acquisition include:

- *User-centered / Participatory* design exercises, wherein design professionals must interact with (e.g.) organizational managers and end users.
- *Knowledge elicitation* exercises, where by definition the sources of "knowledge" (experts) are identified with respect to differential skills or expertise.
- *Educational / Training* meetings, in which (e.g.) end users are familiarized with the emerging product.
- *Usability testing* exercises, in which developers, testers, and end users assess the emerging product

• *Project management* meetings.

Beyond design and acquisition, the USAF has an interest in optimizing collaboration in operational areas such as *multi-operator crew systems*, *command and control systems*, *logistics*, *planning*, and the *organizational re-engineering* aspects of ongoing DOD adjustments to the post-Cold War era. Owing to this broad scope of applicability, the CDT research agenda was framed without specific regard to supporting human factors or ergonomics professionals per se.

More specifically, the August 1993 mission statement laid out the following four task elements:

1) Develop and evaluate procedures and protocols optimized to state-of-the-art media.
2) Develop innovative group-human system concepts.
3) Model and simulate advanced groupware to assess human and technology demands and implementation feasibilities.
4) Transfer emergent group collaboration technical capabilities to industry.

The first task element explicitly linked our work to the state of the art in the communication media underlying collaborative applications of *information technology (IT)*. Based on the term "innovative" connoting the ability to surpass the status quo, the second task element explicitly linked our work to the state of the art in *human computer interaction (HCI)* as it applies to group IT usage. The third task element explicitly linked CDT Lab activities to the current state of research and commercialization in the research area termed *computer supported cooperative work (CSCW)* and those IT applications for team support termed *groupware*. The remainder of this report will present the activities related to these three goals. The issues and experiences relevant to these three task elements have an applicability to a variety of activities not necessarily subsumed within "design" -- e.g., management decision making, group knowledge elicitation, or collaborative document writing. As a result, the CDT research agenda was framed with respect to the demands of collaboration on information technology generally. The fourth element -- external technology transfer -- lies outside the scope of this report.

These goals' allusions to "state-of-the-art," "innovation," and "advanced" all connoted that we be aware of the status of research and development in the relevant areas. We therefore initially prioritized comprehensive assessment of the "state of the art" in terms of research, concepts, tools, and products across the R & D fields targeted by the task elements. Some of the tactics employed in this assessment included: literature reviews; vendor contacts; monitoring on-line news groups; and collecting materials from Internet sources. A large compendium of product information, reviews, academic papers, and further contact information was assembled and continually updated. Selected interactive resources we identified (primarily information sites on the Internet / World Wide Web) are listed in Appendix A.

The second task element's focus on "advanced group-human systems concepts" led us to critically re-evaluate the state of the art in group support tools and devise a new strategy for fitting such tools to their sets of users. The results of these efforts will be discussed later in this report with reference to the *Group Interface (GI)* and the *Unified Interface Surface (UIS)* prototype. More detailed discussion of these efforts will be found in a companion Technical Report (Whitaker, Longinow, & McNeese, 1995). Finally, we conducted studies of human factors in group design processes to provide background for our evaluation of state-of-the-art media and formulation of advanced group-system concepts. Examples of these research efforts are described later in this report and in other publications as noted.

THE SCOPE OF CDT ENQUIRY: THE CDT "TRIANGLE"

The set of research and development areas mentioned as relevant to CDT enquiry was enormous, owing to the topical and administrative links to AKADAM, CSCW, remote teleconferencing, knowledge elicitation, user-centered or participatory design practice, the CASHE "vision," and our diverse sibling project groups within the Design Technology Branch. Planning a specific research program required us to (1) circumscribe our research "territory" and then (2) chart a progressive path of activities through it. We found the most useful device in achieving the initial circumscription of our scope to be the "CDT Triangle" -- a diagram admittedly playing on our own name -- illustrated in Figure 2.

The triadic relationship between collaboration (an interactive group process), design (a constructive task), and technology (specifically information technology) proved very helpful in formulating the CDTeam's agenda. The links between the three nodes succinctly captured the trio of topical areas upon which the CDT Lab work could focus: *Collaborative Design (CD); Collaborative Technology (CT); and Design Technology (DT).* Our interpretation of the CDT Lab mission was to conduct basic and applied research addressing Collaborative Design (CD) and Collaborative Technology (CT) in preparation for leveraging advances in Design Technology (DT).

As a result, we framed our initial agenda to address the CD and CT "legs" of the CDT Triangle, and it will be work in these directions that is summarized in the balance of this report. The next two sections will address Collaboration / Collaborative Design and Collaborative Technology, respectively, to introduce the reader to the topical background and issues of currency which drove our research during the period 1993-1995. Subsequent sections will detail the CDT Lab's infrastructure, approaches to these issues, and specific research activities.

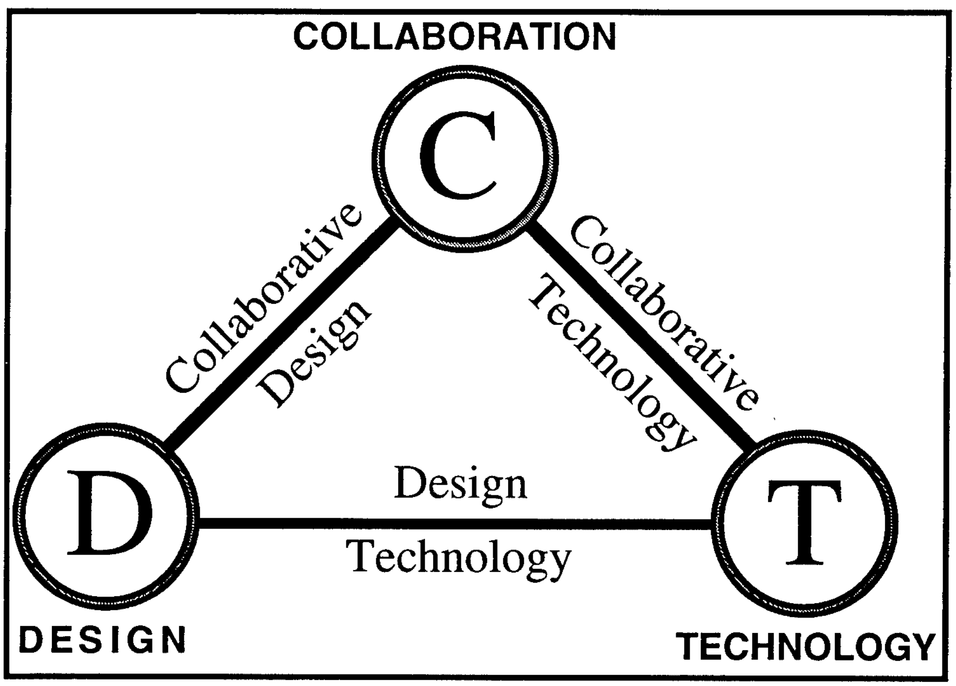

Figure 2: The CDT "Triangle" configuration of research issues

Collaboration / Collaborative Design

The CDT research agenda was tailored to address issues of collaboration in design. The motivations for this programmatic direction lay in current events within the United States Air Force specifically and the design community at large. Design practice had been shifting more and more toward *Concurrent Engineering (CE)*, which the Institute for Defense Analyses Report IDA R-388 defined as "...a systematic approach to the integrated, concurrent design of products and their related processes, including manufacturing and support." Concurrent Engineering approaches to design mandate that all parties to the generation of a given end product (e.g., designers, end users, manufacturers, marketers) be actively involved throughout its design, development, and deployment. In other words, the diverse participants in product development work together in tandem during the whole process, rather than each working his or her "little part" during some part of the overall process.

The novelty in CE is well illustrated by analogy to automobile manufacturing (cf. Whitaker & Essler, 1990). Henry Ford's inception of the assembly line was based on each worker adding to the emerging automobile in a stepwise fashion, then letting the subassembly continue down the line to the next station. Although all the workers on the line could be seen as collectively assembling the car, each station along the way was functionally specialized to the point that the only real "collaboration" among the workers was to accept and pass on the emerging product. In contrast, team-based automobile assembly at Volvo's Kalmar plant in Sweden was based on a small, persistent team of workers assembling a single car from start to finish. Conventional approaches to large systems design followed the Ford model -- linear, stepwise progression from design through manufacture to test and deployment. Concurrent engineering takes the Kalmar approach -- bringing together a team whose members' respective expertise will be applied in concert with their peers throughout the entirety of the production process.

In 1993, the U.S. Air Force officially adopted Concurrent Engineering as *Integrated Product Development (IPD)*, which Major General James Fain, then Commander of the USAF Aeronautical Systems Center, defined as "a philosophy that systematically employs a teaming of functional disciplines to integrate and concurrently apply all necessary resources to produce an effective and efficient product that satisfies customers' needs." IPD was to be accomplished by multidisciplinary *Integrated Product Teams (IPT's)* working in tandem. The USAF adoption of IPD provided CDTeam with a ready-made focus for its work on Collaborative Design.

The groundwork for such work had already been laid in a study involving design professionals from the USAF's Aeronautical Systems Center (ASC), as described in McNeese *et al.* (1993). A panel elicited knowledge from each of seven experienced human factors specialists using the *concept mapping* technique. Each specialist was asked to recount actual experiences, and a concept map was constructed to reflect these experiences plus any generalizations or insights. These individual reports were then compiled into a *summary map* outlining the general issues and insights discernible in the entire set. Although no detailed topical focus had been planned or related to the specialists, the resulting summary map concentrated on specific aspects of design teams' organizational structure, interpersonal relationships, and the influence of these on the resolution of design problems. This summary map portrayed an inventory of contrasts between traditional design / acquisition groups and IPT's. In comparison with the newer IPT's, subjects characterized the traditional USAF design acquisition groups as displaying:

- more formal communication structures (e.g., Critical Design Reviews)
- narrower bandwidth of information exchange
- a more strictly evaluator/monitor role for government representatives
- strict governance by the systems acquisition development procedures
- emphasis on a 'standard' against which contractors must 'get it right'
- strong influence of personality factors

- frequent challenges of expertise due to insufficient understanding of others' perspectives

In contrast with the traditional design / acquisition groups, the subjects characterized USAF IPT's as having:

- less formal, more frequent person-to-person interaction
- less commitment to forcing black and white decisions regarding gray situations
- fewer and less severe design bottlenecks
- increased sense of teamness
- increased levels of accountability
- increased awareness of other disciplines' design constraints, making design tradeoffs less obscure
- lessened adversarial relationships between government and contractor participants
- more impact on actual human factors engineering designs

Overall, the IPD approach was believed to expedite issue resolution and to promote both earlier and better integration of design requirements from multiple disciplines. CDTeam predicated its research on the thesis that the key factors in realizing IPD's apparent benefits were: promotion of intrateam communications, promotion of "flatter" team hierarchies (i.e., a more "peer-to-peer" orientation), and promotion of information sharing throughout the process. These key factors were repeatedly cited in the general literature and success stories in Concurrent Engineering at large. This emphasis on interaction and information sharing was also reflected in the best available data on engineers' problems with CE practices. In a 1993 survey of engineers (Bulleley, 1993), 61% of responding engineers acknowledged their firms had gone to concurrent engineering, and over half of them claimed CE was causing them more stress than prior practices. This result motivated a closer inspection of the survey results by CDTeam. The respondents' five most frequently cited CE drawbacks were:

1) "too many meetings" (52% of respondents)
2) "too many cooks in the kitchen" (38% of respondents)
3) "not enough design time" (32% of respondents)
4) "too many compromises" (23% of respondents)
5) "emphasizes social skills" (18% of respondents)

The "Top 5" CE drawbacks reported by engineers can all be seen as problems relating to the team meetings upon which CE practice relies. The first and third most frequent complaints entail a problematical tradeoff between meeting participation and the sort of design work previously conducted individually. This implies *CE meetings are inefficient* in terms of (e.g.): managing time required for "synchronization" of agendas; managing time required for "coordination" of viewpoints; maintaining consistency across sessions; managing time required for meeting preparation; and managing time required for meeting conduct. We concluded that integrating collaborative technology into existing work formats and across geographical / temporal boundaries (e.g., via wide-area networks) could help in overcoming these efficiency problems.

The second, fourth, and fifth most frequent complaints entail a problematic tradeoff between designers' technical and social skills. These imply *CE meetings are ineffective* in terms of (e.g.): presenting multiple perspectives on the design problem; understanding and appreciating each others' concerns; and formulating consensus. This view is supported by experience from the CSCW community, where up to 80% of meeting time is estimated to be spent on such cross-orientation among interactors (Fuller, 1993). We concluded that collaborative technology support for depicting, manipulating, and contrasting the disparate perspectives of multidisciplinary design team members would address the effectiveness problem.

Because the CDT Lab was a follow-on to the previous AKADAM work, much of this delineation was framed with regard to the issues proven to be critical in that earlier project. The AKADAM experience highlighted the advantages of systems design being *user-centered*, and it demonstrated that user-centeredness could be achieved in practice through promoting *user participation* (McNeese *et al.*, 1993). Most of the AKADAM team's design and re-engineering support activities elicited knowledge from individual subject matter experts (SME's), but others involved sessions in which groups of SME's participated. The AKADAM project demonstrated that its knowledge elicitation techniques could support teams, but those aspects of knowledge elicitation peculiar to team applications were not the foci of the research per se. The CDTeam accordingly switched from devising and demonstrating knowledge elicitation methods for groups (among others) to researching fundamental issues of how information technology and structured group processes (such as the AKADAM methodology) could support design collaboration in concurrent engineering. The next section introduces the specific topical intersection of our knowledge elicitation expertise, current design practice, and CSCW research -- *design rationale.*

Design Rationale: Knowledge Construction in Collaborative Design

Design decision making can be complex, and this complexity naturally rises in proportion to the complexity of the system being designed. What is not so obvious is that complexity in design decision making can vary along another dimension, proportional to the number of communicational and interpretive "passages" that must be traversed in the course of achieving final consensus on (e.g.) requirements specifications. In multidisciplinary design teams, there are a number of such "passages" to be traversed when (e.g.): comparing disparate frames of reference; educating partners about one's own terminology and criteria; explaining conclusions which are not obvious to anyone outside one's own specialty, and the like. Phrased another way, a good deal of the work lies in formulating the background for decision making, not just in the final selection of one or more alternatives. This background is itself a form of expressible "knowledge" in the same sense addressed in artificial intelligence (AI) or knowledge acquisition -- a structured model with its own denotational and/or procedural semantics. In this case, the model augments knowledge of the task domain (e.g., a task analysis) and the emerging artifact (e.g., requirements specifications) with knowledge of the design decision making process as well as the intermediate design decisions made. Such a model of the process, the debate, and the justifications leading to a particular design is termed *design rationale*, which has been defined as:

- "... the design problems, alternative resolutions..., tradeoff analysis among these alternatives, and a record of the tentative and firm commitments that were made as the problem was discussed and resolved." (Conklin & Begeman, 1988, p. 304); or
- "...a historical record of the reasons for the choice of an artifact ..., a set of psychological claims embodied by an artifact ..., and a description of the design space ..." (Lee & Lai, 1990, p. 4)

Some IT tools have been developed to provide a depictive framework within which design rationale is displayed and manipulated. The most widely known such application is gIBIS (Conklin & Begeman, 1988; Burgess-Yakemovic & Conklin, 1990) -- a multi-user hypertext system developed at MCC as a computer implementation of Horst Rittel's IBIS (Issue-Based Information System) planning and design method (Kunz & Rittel,1970; Rittel, 1980). The gIBIS tool consists of a graphical interface allowing users to address and manipulate a common representation of their design discussion, based on these basic units and a set of standard relations. The representational schema employed has three main components. *Issues* depict any topic of discussion. A *position* is any expression which addresses, qualifies, or otherwise informs a given issue. Finally, an *argument* is any expression which (as a propositional unit) either supports or raises objection(s) to a given position. This reliance on a schematic representation is another link

between design rationale and the sort of knowledge acquisition practiced in AKADAM.

Besides gIBIS, other design rationale systems include: rIBIS (Rein & Ellis, 1991) -- a real-time version of gIBIS; ArgNoter (Foster & Stefik, 1986; Stefik *et al.*, 1987) -- a graphical IT tool for displaying positions and arguments in a structured fashion; SYNVIEW (Lowe, 1986) -- a distributed conferencing / decision support tool; PHI (McCall, 1987) -- an extension of the IBIS argumentation model; and JANUS (Fischer *et al.*, 1989) -- an application of PHI to reflect decisions made in kitchen design. SIBYL (Lee, 1990a; 1990b; Lee & Lai, 1990) is a more highly structured extension of gIBIS which adds: (1) a more formal representation language (DRL -- Decision Representation Language) and (2) a decision matrix -- a 2-dimensional grid mapping alternative positions onto specific goal states. The most recent development in the gIBIS lineage is the introduction of an Microsoft Windows-based gIBIS tool called CM/1 in 1994. This PC application provides the functionality of the original gIBIS in a commercial package with a graphic interface.

As a form of knowledge (in the AI sense), design rationale serves a number of useful functions. It records design decisions, enhances "organizational memory," informs subsequent decision making, and explains prior design decisions. Design rationale is most critical for people who must coordinate plans across distance, coordinate plans over time, and explain or justify intermediate and final results. Design rationale is most critical for systems which are large, complex in form, complex in function, and long-lived in service. In terms of both people and systems, design rationale's highest criticality matches the profile of USAF operations. We therefore elected to prioritize design rationale as a focus for our enquiries into collaborative design. As a form of knowledge (in the AI sense), design rationale is amenable to elicitation, depiction, analysis, and inferential manipulation as done in (e.g.) AI's "knowledge engineering". This point of intersection meant that our team's AKADAM experiences, techniques, and tools could be applied to design rationale, allowing us to build our new research program directly upon existing assets.

Design rationale provided CDTeam with a current research topic upon which to focus its work on collaborative design. As a result, the CDT Lab continued to offer the sort of meeting facilitation and knowledge elicitation services which local clients had come to know through the AKADAM project. This reliance on the earlier work had several effects. By drawing on resident expertise and tools derived from the AKADAM work, we were able to minimize our ramp-up costs and expedite the transition to the CDT agenda. By sticking to knowledge elicitation exercises, we obtained some measure of uniformity across the group sessions being studied and a sound foundation for evaluating the results. This approach even facilitated the recruitment of subject groups whose patterns of collaboration we could study. Due to the popularity of the AKADAM work among local clients, we had a ready pool of potential subjects willing to conduct their real-world design activities under our scrutiny. The contrast with AKADAM lay in CDTeam's orientation -- the services were now being provided as concrete exercises within the course of which group dynamics, joint knowledge representations, consensus formation, and human computer interaction could be studied.

As noted earlier, CDTeam had concluded that general research issues in collaborative process were not unique to systems design, as it is typically delineated. Products other than technical artifacts were devised by processes of "design," and we expanded the scope of subject "design" activities to include organizational re-design, Total Quality Management (TQM), Business Process Re-engineering (BPR), programmatic planning, and the creation of concept demonstrations. By providing facilitation services within CDT Lab to such broadly-defined "design" groups and simultaneously studying the resultant activities as instances of collaborative process, we set the stage for that portion of our research work termed *simulation studies*. By examining the collaborative design process in its "natural setting," we accomplished multiple *observational studies*. By formulating and enacting formalizations of the key factors of IPD advantage (e.g.,

design tradeoffs), we were able to pursue *experimental studies.* Finally, by obtaining, evaluating, and developing groupware artifacts, the CDT Lab was able to pursue *technology studies*. All four lines of research will be discussed later in this report. For now, we shall turn to the second CDT Triangle "leg" we explored during this reported period -- Collaborative Technology.

Collaborative Technology

Introduction: CSCW and Groupware

As with most information technology (IT) research, the areas most relevant to our interests are loaded with jargon. The two key labels for classifying our research interests were *Computer-Supported Cooperative Work* (CSCW) and *groupware*. "Computer Supported Cooperative Work" was coined by Irene Greif and Paul Cashman in 1984 as a marketing tag for a vision of integrated office IT support -- "...A shorthand way of referring to a set of concerns about supporting multiple individuals working together with computer systems." (Bannon & Schmidt, 1989, p. 358). Generally, *CSCW* pertains to the overall field of supporting task-oriented teams with information technology. The term *groupware* is most often invoked to reference those products applied in providing such support. This term was first defined by Johnson-Lenz and Johnson-Lenz (1982) to denote "intentional GROUP processes and procedures to achieve specific purposes plus softWARE tools designed to support and facilitate the group's work." (Hiltz & Turoff, 1992). It is important in orienting oneself to emphasize how this initial definition subsumes both IT artifacts and the workplace social systems within which they are deployed (Ellis, Gibbs & Rein, 1991). Bannon and Schmidt (1989) discriminate between "groupware" and group work issues, as does Grudin (1991). Following Johansen (1988), Ellis *et al.* restrict their usage to the IT artifacts, themselves, defining groupware as "computer-based systems that support groups of people engaged in a common task (or goal) and that provide an interface to a shared environment" (1991, p. 40). For the purposes of this report, we shall follow this definition.

Proponents question the precise boundaries of this research and development area, though none question the value of the issues addressed therein. There is a significant body of research, development, and trade literature covering the areas of CSCW and groupware. The reader wishing to more deeply explore the origins, themes, and developments in this area is recommended to Greif (1988); Olson (1989); Bostrom, Watson, and Kinney (1992); Marca and Bock (1992); and Johansen (1988) -- all excellent introductory overviews to this area and the issues it covers. For an analytical overview of how groupware has actually been applied in real organizations, see Bullen and Bennett (1990a; 1990b). The proceedings from the CSCW conferences to date (Austin Texas / 1986; Portland Oregon / 1988; London / 1989; Los Angeles / 1990; Amsterdam / 1991; Toronto / 1992; Milan / 1993; Chapel Hill, North Carolina / 1994) are valuable sources of material at both introductory and advanced levels. Additional sources of basic information are offered in Appendices A, B, and C.

Historical Background: Engelbart's Vision of Organizational IT Integration

In tracing the history behind groupware, one should start with the work of Doug Engelbart, dating from the 1960's. Engelbart is credited with many of the innovations which now make computers easier to use, and he was involved in the creation of the earliest computer-supported meeting environment at the Stanford Research Institute in the 1960's. It is Engelbart's overall vision of how computers can be employed in organizations which both sets the context for these individual achievements and establishes him as a key source of the ideas in CSCW. Engelbart's vision was one in which *knowledge workers* deal with information rather than with physical goods (1982). In addition to manipulating and manufacturing data, they create knowledge of the task, of the means for achieving that task, and of the workplace. Shared information environments provide the milieux within which knowledge workers can augment as well as mutually pool knowledge. Some key features in Engelbart's vision are:

- access to computers for all workers (including easy usability);
- linkages among all workers within an organization via telecommunications;
- storage of the organization's "knowledge" within this shared electronic environment; and
- the means by which the ongoing "knowledge" relating to operations can accrete to the shared environment.

Engelbart himself has pursued this vision over the last 4 decades. A prototype system (called Augment) was developed, incorporating many of the communications / storage / retrieval / documentation functions which today we associate with email, hypertext, databases, and the like. Augment later served as the foundation for data services provided through Tymeshare, Inc., which even later was bought by McDonnell Douglas. Today, Augment is a component of the tools being applied by Engelbart's Bootstrap Institute in his ongoing efforts to investigate the ways in which organizations can implement shared knowledge environments and apply the results toward renewal of large American institutions (particularly corporations) (Engelbart, 1990).

What Delineates CSCW and Groupware?

Some authors have given their attention to discussing work, while others concentrate on products, and this divergence of focus (i.e., products *versus* work processes) has been widely recognized and discussed. Bannon and Schmidt (1989, p. 359) distinguish between "CS" and "CW" in illustrating this divide, while Grudin (1991) contrasts "groupware" with "CSCW." Whitaker, Östberg, and Essler (1989) distinguish between **CS**cw (*Computer Support* for cooperative work -- the technical perspective) and cs**CW** (computer support for *Cooperative Work* -- the social / organizational perspective). This version of the distinction will be employed in this document. A closely related distinction is geographically determined between the product-oriented, CScw tenor of American work and the organizational-oriented, csCW emphasis more common in Europe (Grudin, 1991).

Largely due to these differential foci, CSCW is impossible (and groupware very difficult ...) to precisely circumscribe (cf. Howard, 1987; Bannon & Schmidt, 1989; Grudin, 1991); and Robinson, 1989; 1991). The central notions of computer support and cooperative work provide a basic agenda for discussion. Problems arise, however, when one moves "outward" from this central area and meets with other disciplines and research areas. Some general contrasts can be drawn so as to generally orient our discussion by delimiting the "boundaries" circumscribing CSCW and groupware.

Groupware is not synonymous with any class of IT product. Groupware is explicitly designed to support collective activity among workers, so it is defined partially by the collective nature of the work it supports. Even this qualification fails to precisely delineate the field, because the variety of support systems and strategies is as great as the variety of activities and interactions in which people collectively engage (Johansen, 1989a). As a result, many diverse artifacts are called groupware, with different authors' categories differentially denoting variants and composites within the potpourri. This variety weakens the label's utility in categorizing software applications (Opper, 1988). Conversely, this profligate variety confounds attempts to define CSCW via enumeration of products (cf. Wilson, 1988).

Neither is groupware completely specified by its IT implementation environment. Grudin (1991, p. 6) outlines unresolved contradictory views on delineating "groupware" vis a vis foundational technologies. Engelbart's original support tools for "knowledge workers" (1963; 1982) -- the harbingers of CSCW -- were conceived and implemented in the days of mainframes and dumb terminals. The strong association of groupware products with multi-user environments should not be considered an equivalence relation. In a multi-user environment, many people work simultaneously, but there is no connotation their tasks are interdependent (Whitaker & Essler,

1990; Ellis *et al.*, 1991). Indeed, undue reliance upon analogies drawn from earlier multi-user systems has been identified as one critical factor in groupware failures (Grudin, 1988).

Ellis, Gibbs, and Rein (1991) conclude it is most reasonable to think in terms of a spectrum within which applications can fall as "groupware." They define this "groupware spectrum" in terms of (1) degree of commonality in task and (2) degree of commonality in the (electronic) work environment -- thus spanning both approaches in one loose composite measure. In other words, *specific systems or environments provide only a context in which groups may collaborate; collaborative activity itself is the necessary condition for the label "groupware."*

Groupware is not synonymous with communications. Because groupware implies collaboration, its delineation and implementation are necessarily intertwined with issues of communication. This is reflected in the typical targeting of groupware products for LAN environments (Johansen, 1989) and telecommunications companies' high profile in CSCW literature and the CSCW conferences to date (Grudin, 1991). At the extreme, Wright (1990) addresses CSCW (as distributed group work -- i.e., different time and/or place) as one of several emerging trends within telecommunications itself. Telecommunications, however, is not equivalent to CSCW or groupware. Computer-supported meeting rooms are considered groupware (cf. Johansen, 1989b), but much of the supported communication is enacted in the ambient social space, not through the artifacts themselves. Johansen (1989b) lists many general purpose communication systems in his groupware review, but does so within the broad context of "*technological* support for work group collaboration," basing their inclusion on provision of a medium for collective activities.

These exceptions reveal that access to a common medium within the context of collective activity, rather than communication *per se*, is the fundament for CSCW. This "shared information space" concept is implicit in Engelbart (cf. 1963; 1982) and (termed *shared environment*) is an integral part of Ellis *et al.*'s (1991, p. 40) definition for "groupware." Both Robinson (1991) and Bannon (1991b) allude to the work of Thompson (1984) with regard to this concept, but do not make any claim that Thompson is the origin of the phrase in the sense that it has become an important "CSCW specific concept" (Robinson, 1991). Bannon and Schmidt (1989, p. 364) identify "sharing an information space" as a "core issue for CSCW"; and and De Michelis (Butler Cox Foundation, 1990) cites "information sharing" as the key support for collaborative activity. In all these cases the focus is on common access to task-specific information rather than on the communication links via which that access is realized. This distinction between the technical foundation (communications infrastructure) and the operational benefit (shared information space) is addressed in Bannon (1989) and in Grudin's comments (1991) on databases and CSCW. In other words, *communications systems are groupware only to the extent they specifically lend support to some collaborative activity.*

CSCW is not defined solely in terms of cooperation. The term CSCW becomes no clearer when approached from the direction of work process. After an extensive review, Bannon and Schmidt (1989) conclude "...the term 'cooperative work' is the general and neutral designation of multiple persons working together to produce a product or service" (p. 362). Their lack of further specificity is understandable, because "cooperation" becomes a very problematic subject under closer scrutiny. Those who have gone this route -- retaining a broader social scope and addressing general interpersonal factors -- have ended up at the extreme of framing "cooperation" as a purely sociopolitical phenomenon.

Howard (1987, p. 175-176) criticizes such extreme views of cooperation as being "...not merely a description of the way work is but a prescription for the way it ought to be." Bannon and Schmidt (1989) close off this line of definition when they state "(t)he concept of cooperative work does not imply a particular degree of participation or self-determination on the part of the workers, nor a particularly democratic management style" (p. 362). This assertion is substantiated by

experiences in groupware implementation. Caracik and Grantham (1988) describe users' rejection of The Coordinator™ with reference to its perceived negative impact on autonomy and equality; Bullen and Bennett (1990a; 1990b) note the social impacts of groupware implementations; and Whitaker, Östberg, and Essler (1989) suggest that groupware products' intrinsic presumptions may occasionally violate mores of national as well as corporate cultures.

Like the earlier points discussed, consideration of team work as the sole discriminant in CSCW leads to ambiguity. If a CSCW application is defined by work setting, and "*all* human activity is in some sense 'cooperative' " (Howard, 1987, p. 175), it is difficult to see how any system could avoid being so categorized. If one speaks broadly enough about the "task" of an entire organization (corporation, agency, etc.), then one can subsume all workers within a group whose goal is achievement of this task, diluting the idea to near-uselessness. In other words, *the activity of interest is defined jointly in terms of interacting collaborators and shared goal(s), not in terms of any a priori quality defined socially or politically.*

CSCW is not delineated with strict regard to organizational boundaries. Skeptics have long viewed CSCW as a repetition of the *office automation* fad of the late 1970's, emphasizing integrated production support for entire organizational units (e.g., Wohl, 1989). With specific regard to strict organizational delineation, such comparisons are unfounded. Grudin (1988) illustrates populations affected by CSCW implementations do not necessarily correspond to the entirety of an organization. Conversely, consideration of CSCW need not be properly constrained to a single organization. Toffler's (1990) interconnected "power mosaics" (flexible collaborative networks, successors to monolithic enterprises) rely on inter-organizational communication and coordination, and they will provide a major impetus to groupware proliferation. Suomi (1989) and Hart and Estrin (1990) provide general overviews of IT systems for coordinating operations across organizational boundaries, while Engelbart (1990) describes an example of "knowledge domain interoperability" from the aerospace industry, spanning some 6,000 separate companies.

Groupware cannot, therefore, be precisely mapped onto organizational units. This is just as well -- if we accept Toffler's (1990) vision of emerging "flex-firms" and the "power mosaics," then (respectively) internal architectures and rigid inter-organizational relations are becoming obsolete as useful delimiters. What, then, is a more appropriate scope for consideration? Grudin (1988) suggests addressing the aforementioned conflicts by restricting consideration to "...smaller or more homogenous groups," claiming "...there may be less bias when only peer-peer communication is involved than when the communication moves vertically through the organizational hierarchy" (p. 87). Markus and Connolly (1990) extend Grudin's discussion by reference to interdependence among users of specific applications, rather than classes or subunits defined with respect to the organizational map. In both cases, discussion occurs against a backdrop of organizational structure, but analysis defaults to task-oriented relations among interactors. In other words, *the relations delimiting the groups of interest are relations of concerted activity, not relations of organizational membership or ranking.*

CSCW is not isomorphic with other disciplines or research fields. A certain interdisciplinary flexibility is implied (and demanded) in addressing the confluence of IT and group activities. Grudin (1991) identifies the MIS and HCI communities as "...the major contributors to groupware development and CSCW research" (p. 12). Ellis, Gibbs, and Rein (1991) list "distributed systems, communications, human-computer interaction, artificial intelligence (AI), and social theory" as "five key disciplines or perspectives for successful groupware" (p. 44). We must take care to distinguish the perspectives of research fields intersecting CSCW from that perspective which (however indistinctly) identifies CSCW itself. This is critical, owing to (1) the diversity of venues in which CSCW research is presented as well as (2) the diversity of research presented in venues ostensibly centered on CSCW.

An example of the first case concerns the human-computer interaction (HCI) / human factors

(HF) community. CSCW has been a persistent topic at the ACM CHI conferences, and ACM's SIGCHI co-sponsors the North American CSCW conferences. However, the ability of HF/HCI research to contribute to CSCW is limited. The HF community has tended to address "knowledge workers" in terms recycled from the days of mechanical automation -- functionality, efficiency, and the impacts of technology on individual workers. HCI's attention to the interface between computers and human "users" narrowly addresses an artifact's functionality with respect to an individual's physical and cognitive capacities (Grudin, 1990a; 1990b). Historically, this viewpoint derives from HF research's original industrial setting, and it is perpetuated by HCI's reliance on laboratory experimentation, isolating system usage from its workaday context (Bannon, 1991a).

This results not only in impractical abstraction and rapid obsolescence, but (more importantly) a blindness to group support issues such as interaction (Bannon, 1991a). This blindness is not overcome through simple analogies between functional units. Work teams are flexible, dynamic, often transient social networks presumably best analyzed via social science techniques. HF/HCI (as a scientific/engineering enterprise) leaps from the level of the individual to that of a composite, indivisible unit (company, union, etc.). The complexities of work group interactivity cannot be addressed via extrapolations from the individual user to the organization itself or extrapolations from individual users to entire categories or classes of workers.

An example of the second case concerns Scandinavian participatory design (PD). The strong association of PD with CSCW is understandable to the extent that: (1) both fields emphasize the social and organizational aspects of working life and (2) collaborative design exercises are instances of "cooperative work" (Whitaker, Essler, & Östberg, 1991). On the other hand, the workplace collaboration emphasized in CSCW is not synonymous with the workplace democracy emphasized in PD, and there is a big difference between collaborating on an IT design and designing IT for collaboration. PD is often pursued with groups of workers, but there is no presumption the system being designed is groupware. Conversely, much of the design activity characterized by participatory design writers as "cooperative" is accomplished without any direct IT support.

There are as many points of divergence as of correspondence between CSCW and the other fields to which it exports and from which it imports reported research. HCI has informed us on some aspects of CScw, but it is conceptually and methodologically ill-equipped to address csCW (cf. Bannon, 1991a). PD has addressed csCW, but is not intrinsically linked to groupware -- either in terms of its tools or its products (Whitaker, Essler, & Östberg, 1991). In other words, *CSCW is interdisciplinary and irreducible to either CScw or csCW. Work ascribed to CSCW should be assessed in light of the "perspective" from which it is undertaken. Work imported from other research areas should be qualified with respect to their native "perspectives."*

CSCW Defined by Task Environment: The Example of Johansen

Robert Johansen (1989b) provides a taxonomy of groupware applications using distribution in time and space to delimit application categories, as partially replicated in Table 1. He categorizes some of the 17 different types of group support applications he identifies (Johansen, 1988; 1989a) into subsets based on the dispersion or copresence of collaborating parties in time and/or space. This categorization scheme has proven particularly useful both as a means of classifying groupware products and as an illustrative device for demonstrating the types of work environments addressable with such products. Johansen et al. (1991) claim the inspiration for the time/space classification came from DeSanctis and Gallupe's (1987) discussion of GDSS. One advantage of Johansen's approach is that newcomers to the notion of CSCW can easily grasp the time / space permutations and his mapping of product classes onto them. Also, by making time and space the key dimensions for his matrix, he has managed to avoid the thorny issues of what one means by collaborative work and the non-informative nature of a simple listing of products. The result is a perspective which is useful without either forcing *a priori* decisions on ill-defined or vague

characteristics (e.g., mutuality of goals, reciprocal benevolence) or limiting oneself to any collection of specific market entities.

Table 1 CSCW Applications Based on Distribution in Time and Space (Adapted from Johansen, 1989b)

	SAME TIME	**DIFFERENT TIMES**
SAME PLACE	FACE-TO-FACE MEETINGS Copyboards PC projectors Meeting rooms	ADMINISTRATION / DATA MANAGEMENT Shared files Shift work
DIFFERENT PLACES	REMOTE MEETINGS Conference calls Data sharing Video/Tele-conferencing	RELIANCE ON COORDINATION Electronic mail Forms management Voice mail Structured messaging

CSCW Defined via Functionality: The Example of De Michelis

A more recent discussion of CSCW -- De Michelis (1990) -- differs from the CScw and csCW viewpoints in attempting to categorize cooperative work processes to provide a means for discussing specific software applications. His approach concentrates on the mode of cooperative activity, rather than on a comprehensive definition of cooperation itself. De Michelis does not attempt to define what he means by "cooperation." Instead, he notes a trend toward the use of task-directed groups in modern enterprises and claims those groups are "...defined by the pattern of commitments that group members make with each other and with third parties" (p. 2).

Having taken the group as his focus, De Michelis proceeds to delineate three different categories of cooperation: *coordination, collaboration,* and *co-decision.* Coordination is that process by which group members organize and/or synchronize their actions within the framework of a task. Collaboration consists of those activities through which multiple actors work together on a given task. Co-decision is an extended form of collaboration in which the task is reaching a decision. Based on this trinary distinction, De Michelis then proceeds to discuss specific types of support systems developed to date. He does not address a general process of "cooperation," so it is difficult to assign his analysis to the csCW camp. Because he is proceeding from a basis of work style, it is difficult to see him as purely in the CScw vein.

If one looks carefully at De Michelis' classifications, the boundaries among them immediately blur, if not disappear entirely. De Michelis himself implies that co-decision is a variant on collaboration. Coordination can be re-interpreted as either (1) a form of collaboration within which the goal is resource allocation and/or synchronization; or (2) a form of co-decision with the same focus. Clearly, this trifold framework cannot be maintained as a general analytical tool, although it has merit as an illustrative device. More important than his absolute accuracy is De Michelis' shift of definitional emphasis from a general notion of "cooperative work" to more specific, functionally delineable classes of activities. Whether or not one accepts his view of coordination, collaboration,

and co-decision as fundamental categories, they provide a useful means for addressing the types of activities subsumed in CSCW without falling prey to the ambiguities and subjective values which have plagued attempts to define "cooperative work" generally. Similar to Johansen, who improved the "focus" of product enumerations, De Michelis enhances the clarity with which the activities are addressable.

Johansen accomplished his clarification by adding the referential dimensions of time and space. De Michelis makes similar progress by adding discriminatory criteria of specific work goals. The goal of coordination concerns the *plans* for accomplishing a given task; the goal of collaboration concerns the *actions* by which that task is accomplished; and the goal of co-decision concerns *policies* with regard to some task or topic. These descriptions' relative concreteness derives from their being phrased in terms of goals or results. De Michelis' primary contribution is therefore the addition of these goal-directed criteria, which enables him to address activities more precisely than earlier CSCW analysts.

CSCW Defined by the Existence of Groups

Early attempts to define CSCW as an area of interest have fallen either into the CScw or the csCW foci. The writers who have managed to somehow surmount the problems of this dichotomy -- Johansen and De Michelis -- have done so by shifting focus. In the case of Johansen (who refined the CScw angle), the focus is moved to a matrix of time and space parameters. In the case of De Michelis (who refined the csCW angle), the focus is moved to variations among task goals and/or results. In both cases, the dichotomy is circumvented by ceasing to see CSCW (and CSCW products) as being defined via some vaguely defined "collective activity" and instead coming to view whatever is identifiable as collective activity as being defined with respect to something more tangible -- an identifiable group who (among other things) share a task and the means for accomplishing that task.

In the case of Johansen, this is illustrated by reference to parameters which map relations among people (not products) who are distributed in time and space. De Michelis (1990) explicitly takes the stance that the fundamental distinction involves collections of individuals rather than some particular variety of work, stating whatever activities we categorize as *some* sort of cooperative work are known to be thus categorizable by reference to discernible groups and the "...different types of objectives, communication, and relationships..." (p. 2) holding among their members. In other words, *one key criterion for discriminating this ephemeral CSCW area is the group itself* -- neither some feature or quality of its activities nor some specific character of the tool(s) it employs (Whitaker & Essler, 1990). Dimensions or features pertinent to this criterion are:

- Identity of the set of specific individuals which delineate the group as a collection of people;
- Identity of the network(s) of interactivity among this set of individuals;
- Identity of the roles or functions characterizing each individual's participation in the group;
- Identity of the task or goal which delineates the group as a functional unit.

This emphasis on the group (or workplace social system) is not offered as an exclusive alternative to either time/space parameters or goal specifications; indeed, all three of these aspects mutually influence each other. One can offer examples of groups which do not operate in a collaborative fashion (e.g., the set of all users in a centralized multi-user system), and one may point to software tools designed for individual users which are nonetheless employed for collaborative ends (word processors used during small group brainstorming sessions). However, *there is no such thing as collaboration without there being a group thereby co-defined* -- delineation of a "group" is therefore of particular importance in delineating "group work." Taken together,

characteristics of the work environment, the work results, and the work group *jointly* define those workspaces which have heretofore been addressed by CSCW researchers. Furthermore, they accomplish this through reference to specifiable elements (e.g., time, space, goals, results, actors, and patterns of interactivity).

The shortcomings of CSCW characterizations critiqued earlier derived from assuming the artifacts or work activity exhibiting specific styles (e.g., mutuality of goals; equality of empowerment) were determinant. Johansen's and De Michelis' critical improvements concern criteria which are themselves defined relative to participants in a given collective activity. Time and space intervene between workers, not just their tools. Goals and results are determined, attempted, and evaluated by workers, not some objective guarantor. In other words, *groupware is identifiable only with respect to groups, and group work is identifiable only with respect to interactivity.* Based on this analysis, we felt confident we could proceed with CSCW-relevant research framed in terms of concrete project teams, circumstances, and parameters.

<ins>Summary</ins>

CSCW is not comprehensively characterized either by artifacts or activities. Analysis from the basis of stereotyped group activities (i.e., csCW) leads to prescriptions for reconciling sociopolitical factors (e.g., empowerment) when intervening into workplaces portrayed as microsocieties (e.g., PD). This orientation is not necessarily informative on *technological* interventions. Whitaker, Essler, and Östberg (1991) suggest that Scandinavian PD's true subject matter is organizational redesign rather than the design of IT artifacts, based on case examples where participatory practices were applied to model the workers' organization in preparation for IT development. Analysis from the basis of work tools (i.e., CScw) leads to prescriptions for reconciling human factors (e.g., performance metrics) when intervening into workplaces portrayed as functional units (e.g., HF/HCI). This orientation is not necessarily informative on *social* interventions. This is not to say the specific fields mentioned (PD and HF/HCI) are of no use to CSCW researchers. The reciprocal influences of social and technical factors require that analysis and intervention be sensitive to both sides. The complementary blindnesses of (extreme) CScw and csCW require that progress will entail explanations spanning individual actors and groups of interactors.

Consideration of groupware implementation should begin with identification and evaluation of the work team itself. The characteristics of the work environment and the work group *jointly* define those workspaces which are amenable to groupware solutions. The specifiable elements emphasized in useful characterizations of CSCW settings (e.g., time, space, goals, results, actors, and patterns of interactivity) all pertain to the team, its members, and the patterns of interactivity among them. Taken in conjunction with the preceding conclusions, this means we should explore workplaces neither as unitary microsocieties nor as collections of information processing units. The common link between the csCW (e.g., PD) and the CScw (e.g., HF/HCI) "perspectives" is the individual human. However, in the former perspective the individual is often subsumed within a bloc (i.e., linked into the workplace social system only in terms of a depersonalized role), while in the latter the individual is often regarded only in the context of direct engagement with an IT system (i.e., not in the context of the workplace social system). Phrased another way, the csCW perspective sometimes abstracts the worker as a unit of socio-political activity, while the CScw perspective is evident in HCI/HF work which stereotypes workers in terms of "user models."

CDT RESEARCH INFRASTRUCTURE

CDT Lab: A Reconfigurable Group Testbed

In September 1993 the CDT Lab began its "ramp-up" process by acquiring a large laboratory space and requisitioning equipment to set up an advanced technology suite. Our plan was to construct a modular, flexibly-configurable testbed providing (with IT support) a unified milieu for group activities and a simulation platform for both co-located and remotely distributed team tasks. Because we planned to follow the example of AKADAM and exploit opportunities for evaluating collaborative technologies in the context of real-world tasks (e.g., USAF design projects), we had to ensure that the CDT Lab was equipped to handle such tasks' demands. This need for concrete utility in workaday operations further constrained us to equip the CDT Lab with some degree of conformance or compatibility with the IT support already employed in those operations.

As discussed in the introduction to CSCW and groupware, this area of research is technology-intensive. Even for the simplest case of equipping a meeting room (e.g., the AL/CFH Multimedia Room) for electronic display and software support, a potentially high investment in hardware and software is unavoidable. Affording collaborators individual access and control to electronic media multiplies this unavoidable investment in a roughly geometrical fashion. The CDT Lab mission statement's emphasis on the "distributed" aspect further increased (1) the reliance on technology in setting our research context and (2) the explicit and implicit costs for our ongoing work. The increase in reliance resulted from the IT infrastructure's role as communication medium as well as task tool. The increase in costs resulted from the overhead needed to provide communications channels overcoming collaborators' separation in time and / or space.

Because our research infrastructure needed to provide for both the co-located and distributed scenarios, we faced the prospect of very high ramp-up costs. This was primarily due to the inherent resource redundancies of (1) providing similar support to multiple collaborators within a team (e.g., computer workstations and groupware) and/or (2) providing for similar team scenarios in distributed settings (e.g., room-to-room video teleconferencing). Given our finite budgetary means, we therefore devised our initial laboratory architecture in such a way as to:

- Maximize the utility of CDT Lab assets across the range of time / space scenarios.
- Maximize the uniformity of overall IT assets (especially the computers) within CDT Lab itself.
- Maximize the compatibility of CDT IT assets with those already employed by potential USAF clients.
- Maximize the utilization of existing AL/CFHD assets as auxiliary resources for CDT Lab.

The following sections will outline background issues and our planning with regard to physical, computing, and communication resources.

Physical Factors in Group Support

The physical meeting environment (e.g., a computer-supported conference room) has long been recognized as a problematic component of the group meeting support "package." Physical (architectural, lighting, seating) factors have been the subject of much research (e.g., Ferwanger, *et al.*, 1989; Mantei, 1988; Olson et al., 1990), because the character and affordances of the room setting influence the decision making process. Such influence is typically manifested through constraints on representational support and constraints on the available modalities for dialogue. For example, Ferwanger *et al.* (1989) cite several ways physical arrangement of a meeting site can influence interaction either through direct functional biases or tacit social cues. The types of design tradeoffs to be considered in computer-supported meeting room design are well-illustrated by two

similar facilities in Ann Arbor, Michigan -- the EDS Capture Lab and the University of Michigan's Collaboration Technology Suite within the Cognitive Science and Machine Intelligence Laboratory (CSMIL).

An example of the attention physical layout requires is the evolution of the central conference table at these two facilities. At EDS Capture Lab, participants originally had vertical computer displays, angled toward the common wall display at the end of the table. This was meant to minimize the distance between the individual and group displays, so that one need only look up from his/her CRT to see the wall display. This well-intentioned layout proved disadvantageous in use. First, the vertical individual displays were partial obstacles to direct face-to-face interactions among participants. Second, the viewing of both displays in such close (angular) proximity seemed to result in a lack of "visual privacy" for each individual display. Third, the architecturally-enforced orientation to the common wall display conflicted with the participants' need to orient to each other during direct interaction. Finally, participants reported physical stress and discomfort from the angled arrangement (Mantei, 1988).

The final configuration of the Capture Lab central table required multiple iterations of prototyping, evaluation, and re-design. The result was a unit structure coordinated with the room's decor. The participants sit around the table as if at a conventional conference table -- facing inward toward the center. Their Macintosh displays sit squarely before them, sunken into the table surface at a fixed angle. To the left of each display, a panel of the table surface may be lifted to expose a recessed cavity in which each participant's mouse and a floppy disk drive are stored. Individual keyboards are stored in drawers beneath the table. This "hiding" of the storage cavities, the unit table surface, and even the use of compact Apple IIGS keyboards all contribute to the intended maximization of usable table space. The overall effect was an enhanced conference table, with plenty of room for "low-tech" accessories (documents, files, etc.). Generally speaking, the Capture Lab's approach emphasized features finely tuned to the characteristics of the meeting room (Docherty, 1992).

In contrast, the CSMIL Collaboration Technology Suite's table is actually a collection of modular computer desks (called ELMERs) developed by Steelcase Corporation (one of the facility's corporate sponsors). These units were designed to provide maximum flexibility across many conceivable room layouts and workstation display units. To that end, they feature (1) polygonal desktop surfaces, so that they can be arranged in groups of varying size and angular orientation and (2) motorized supports for their large CRT units. These supports, controlled by foot switches, can position the CRT horizontally (flush with the desktop surface), vertically, or anywhere in between. CSMIL outlined specifications for the ELMERs allowing them to handle a variety of computer equipment -- particularly a wide range of monitors.

Such flexibility has been obtained at a cost. The ELMERs are heavy (i.e., not easily moved about to take advantage of the promised flexibility), and due to the foot switches leg room is uncomfortably constrained. The design for (and use of) the largest available monitors results in much desktop space being lost. Finally, the polygonal shape of the desktop surfaces reduces the area available for use when the desk units are joined in a "square" arrangement. At the point(s) where the units meet (i.e., the "corners") the polygonal shape results in open gaps in the composite desk surface. Even though maximum available table space (e.g., for papers) was cited as a desirable feature, the Steelcase design was deficient in this regard. Generally speaking, the CSMIL approach to group work surfaces has emphasized flexibility and functionality.

A second example (concerning flexibility of information display rather than physical layout) can be seen in each facility's attitudes toward whiteboards as group displays. At the EDS Capture Lab, a pair of whiteboards were provided on the wall opposite the group electronic displays. Mounted within a wall niche, they were normally hidden behind wooden panels. As reported in Docherty (1992) the use of whiteboards' was discouraged in relation to use of the electronic displays. At the

CSMIL Collaboration Technology Suite, two entire walls of the meeting room were made up of whiteboard panels, and participants were not discouraged from using them as they saw fit. In this respect, the CSMIL facility seemed to be an environment more suited to open-ended "brainstorming." In contrast, the EDS Capture Lab imparts a degree of focus with respect to the electronic support tools.

Physical architecture issues don't end with the deployment of information technology and other meeting tools. Both facilities reported significant problems with cables and connections -- e.g., numbers of cables, interference among lines, inflexibility with regard to (re-)arrangement, and how to hide cables. In the CSMIL facility, cable layouts restricted (re-)configuration options for the ELMER units. Because multiple units could not be easily or quickly rearranged, the CSMIL researchers were not able to take full advantage of their intended flexibility. Another problem concerned the length of cable required to connect the workstations with the file server(s) and other attendant units in an adjoining room. The CSMIL facility ended up paying a large fee for dedicated cables (especially for their video leads), while at the EDS Capture Lab a resident "hacker" spent much time coming up with a solution. Our experience in CDT Lab confirms the experience at these other two facilities. We had to regularly rely on local technical staff to overcome connectivity problems. Our laboratory space had suspended floors and ceilings which facilitated laying and rearranging cables as needed, and we needed to do this on a regular basis.

As reported in Docherty (1992), EDS Capture Lab had significantly changed in its short history, but staff members indicated their facility's architecture, though sophisticated, was still a prototype. Their conclusion was that "when you build one [meeting] room, you'd better be building a second one" -- both to allow for evolution and to promote research opportunities. We believe that (1) integrated group interface capacities must be based on attention to such physical / architectural factors and (2) no single physical group workspace architecture is likely to satisfy all users at all times. Our CDT Lab planning was therefore directed at providing for flexibility in terms of both situational usage and long-term evolution.

CDT Lab Physical Architecture

In September 1993, the CDT Lab occupied its allotted physical facilities, which included researchers' workspaces, a group meeting/research space, and auxiliary space for technical support / office expansion / observation deck development. Some furnishings were transferred from the previous AKADAM worksite, and the remainder (in fact the majority) were assembled by recycling office and laboratory furniture from our own and adjacent buildings at Wright-Patterson AFB. Our location within a large military site (with a well-developed inventory recycling effort) enabled us to furnish our new work and research space at what was effectively no net cost. Owing to the scale, regular turnover, and uniformity of the site's equipment inventory, we found that with some patience it was possible to obtain comparable or matched items such as chairs and tables.

Approximately one-third of the CDT Lab's physical space was dedicated to the Group Workspace -- a meeting and collaboration area equipped so as to be flexibly reconfigurable as needed. The Group Workspace served as a meeting room for CDTeam, a working site for facilitating clients' tasks, a demonstration / presentation venue for CDT work, an experimental site for CDT studies, a prototyping venue for group workspace configurations, and auxiliary working space for guest researchers and interns.

The Group Workspace was approximately 15 feet by 25 feet in size, with an 8-foot ceiling. The ceiling and floor were composed of suspended tiles, allowing wires and other equipment to be flexibly mounted and reconfigured. The furnishings consisted of:

- (1) Moveable computer work desk with chair
- (1) Fixed table supporting the LCD projection system

• (7) Wall-mountable whiteboards ranging in size from 30" x 40" to 4 feet x 8 feet
• (1) Free-standing whiteboard (pivotable to provide double its 4 feet x 6 feet area)
• (1) 60" x 80" projection screen mountable on the wall
• (2) Work tables which could be arranged as needed (e.g., one square conference table; two panels)
• A variety of office or conference room chairs

With the exception of the projection screen, all the Group Workspace furnishings were obtained by recycling equipment already available locally. The various pieces of furniture were re-arranged as necessary to fit the number of participants, the type of meeting, and other factors. Cameras, microphones, and other equipment were installed or deployed on an "as-needed" basis.

IT Infrastructure

The initial CDT Lab configuration included 7 Apple Macintoshes, divided into 5 main workstations and 2 smaller Macs for auxiliary use. The main workstations were linked into a 10Base-T Ethernet LAN and (via our local VAX server) to the Internet. Two additional terminals provided direct access to the VAX server. We planned for a variety of innovative input / display / control devices (e.g., the Apple Newton™ as a pen-based personal interface unit). Public domain, shareware, and commercial software tools (e.g., ShrEdit and Aspects™) provided collaborative writing, brainstorming, and drawing capabilities. Other groupware products were occasionally acquired by or referred to CDT Lab for usability assessment. Additional CDT software included concept mapping tools deriving from the earlier AKADAM work, the MacSHAPA tool for exploratory sequential data analysis (developed in part with Armstrong Laboratory support), and a wide array of mainstream software applications and utilities. Our group display projection system was comprised of a Sharp QA-1650 color LCD projection panel and a high-intensity DuKane 4003 overhead projector.

During the winter of 1993-1994, the Human Engineering Division shifted from the centralized VAX server to a microcomputer-based, decentralized LAN architecture (Novell NetWare™ and WordPerfect Office™ / GroupWise™). At the close of this transition, the direct terminals to the VAX server were disconnected, and the CDT Lab Macintosh workstations (now equipped with TCP/IP software) were capable of direct Internet access. At that point, the CDT Lab workstations were configured with publicly available software packages such as TurboGopher and NCSA Mosaic. This set the stage for wider monitoring of relevant developments in CSCW, networking, and the like, thus augmenting CDTeam's abilities to remain abreast of the state of the art. It also set the stage for evaluation of tools for creating and maintaining World Wide Web materials using the HyperText Markup Language (HTML).

Video Link

The CDT Lab was the Human Engineering Division's second collaboration facility and CSCW research testbed. The Division's Multimedia Room is an operational meeting / presentation site with: an electronic whiteboard, large group video display, video equipment, Macintosh Quadra, multimedia support software, 35mm slide and overhead projectors, teleconferencing equipment, and visualizer. CDT Lab installed video cameras in the Multimedia Room to allow monitoring and recording of meetings. Attached to the Multimedia Room was a control room with extensive audio and video recording and editing equipment. This facility was employed in and of itself for empirical studies of collaborating real-world design professionals (cf. the later section on the TRACE experiments and Brown, Selvaraj, Whitaker, and McNeese (in press)).

The plan for CDT Lab's research infrastructure extended the Multimedia Room's role beyond simply being a second experimental site. Video teleconferencing (both desktop-to-desktop and room-to-room) was a recurring item of interest for CDT Lab's sponsors and clients. We realized

that the typically high ramp-up costs for video teleconferencing could be reduced to a tractable level by exploiting access to the Multimedia Room's existing video support equipment (e.g., editing tools; mixers; switching panels). Furthermore, we recognized that linking the Multimedia Room with the CDT Lab would provide us a testbed within which to test video conferencing technologies. Precedents for this sort of "in-house" video testbed include the Decision Room at Southern Methodist University and the Decision Laboratory at the Claremont Graduate School (Gray, 1992). The former was not finally implemented, and the latter was only recently reaching operational status.

During the spring and summer of 1994, we constructed a multichannel data / audio / video link between the Multimedia Room's control room and the CDT Lab. On the Multimedia Room end, this link was tied into the existing control room equipment. On the CDT Lab end, the link terminated in an array of control / recording equipment assembled from available local inventory (e.g., used or remainder items in storage). By making the CDT end of the video link 100% "recycled" equipment, we further minimized the start-up costs for establishing a video conferencing testbed. These two linked rooms provided us a single-site capacity to simulate all dyadic permutations of individual / group interactivity in remotely distributed scenarios.

CDT RESEARCH APPROACHES

Overview / Summary of Issues

As described earlier, the CDT Lab's research foci entailed covering a wide range of topical and analytical territory. Not surprisingly, this diversity of issues and interests was determined to exceed the ability of any one research approach to manage. Based on theoretical concerns, prior experiences, and circumstances, we subdivided our research activities into four basic categories:

- *Experimental studies* in which we monitored and analyzed subjects' actions within settings configured in conformance to research paradigms carefully contrived to test issues of collaboration in design (particularly the identification and negotiation of design tradeoffs). This approach can be characterized as conducting artificial tasks in artificial settings toward the goal of testing known or suspected parameters of collaborative behavior. The experimental studies addressed the "CD" (collaborative design) leg of the CDT Triangle.
- *Observational studies* in which we either (1) observed design professionals in the course of their actual design collaborations or (2) elicited, compiled, and analyzed design professionals' self-reports of critical success factors for collaboration in multidisciplinary design teams. This approach can be characterized as carefully monitoring actual tasks in their natural settings toward the goal of identifying new or affirming prior parameters of collaborative behavior. The observational studies addressed the "CD" (collaborative design) leg of the CDT Triangle.
- *Simulation studies* in which we monitored and analyzed the behavior of design (or other) professionals within settings wherein one or more human factors aspects of information support or technology were themselves the subject of interest. This approach can be characterized as conducting natural tasks within settings where the functional relationships between the participants and their support tools were manipulated toward the goal of identifying new or affirming prior parameters of collaborative behavior. The simulation studies addressed interactions between the "CD" (collaborative design) and "CT" (collaborative technology) legs of the CDT Triangle.
- *Technology studies* in which we either (1) evaluated groupware and other relevant technical artifacts or (2) developed novel technology addressing issues related to the other three categories of research. The technology studies addressed the "CT" (collaborative technology) leg of the CDT Triangle.

Figure 3 illustrates how these four types of research activity relate to the issues delineated in the "CDT Triangle" (cf. **Figure 2**). Ours was a two-stage program. First, we sought to better understand collaborative design activities (Track 1A) and technological support for them (Track 1B). The second stage was to carry forward research results to constructively improve design technologies (processes and tools).

In the following sections, we shall describe each of the four research categories in more detail, illustrating our progress along Tracks 1A and 1B of the research plan with specific examples. Some of the examples represent work which has been already reported in the literature or will soon appear in the literature. In those cases, we shall provide references for the reader interested in following up on the information in this report. Some of the examples represent studies involving teams of CDT Lab clients within the USAF. Owing to confidentiality constraints deriving from USAF practices generally or particular agreements between CDTeam and clients, we shall not identify clients more specifically than by programmatic affiliation nor necessarily detail the subject matter of their collaboration.

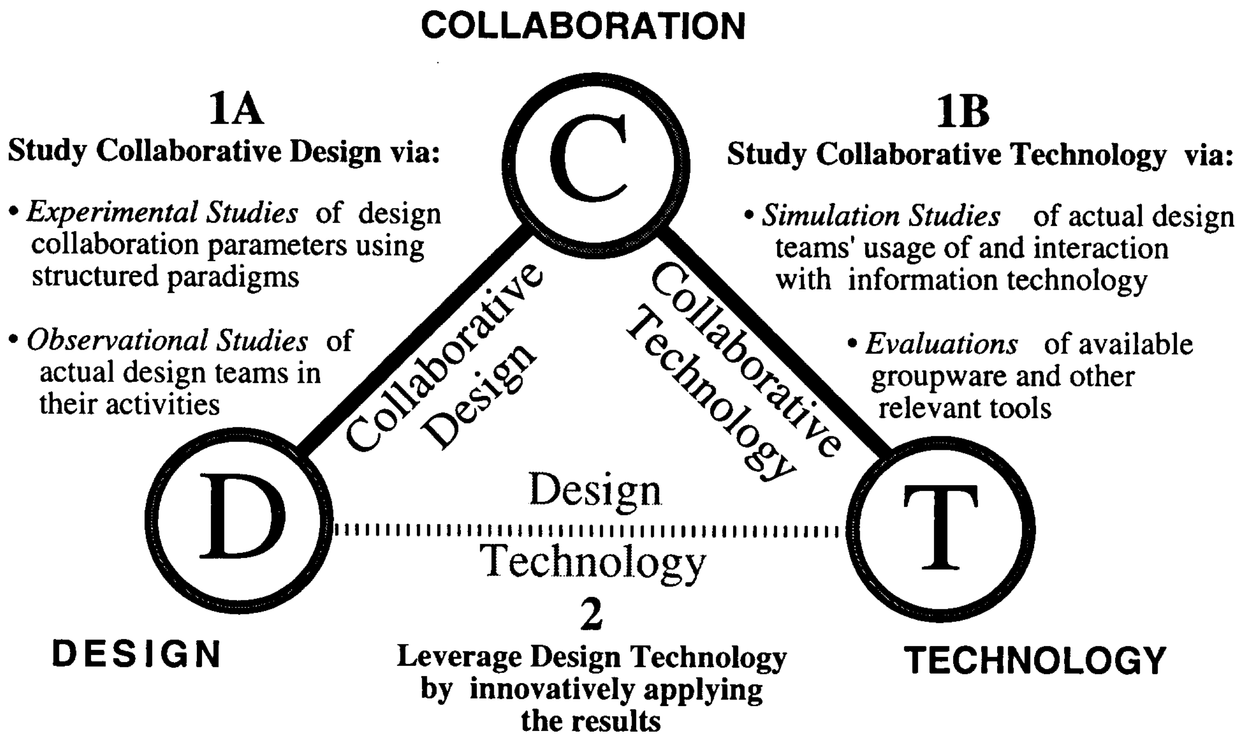

Figure 3: The CDT Lab's issue-oriented research strategy

CDT Lab Experimental Studies

The experimental studies component of the CDT Lab agenda was intended to produce empirical investigations of collaborative design activities. This mode of enquiry focused on the conduct of test subjects within a contrived task setting. The construction of such tasks (or paradigms) was therefore of great importance. At the time of the CDT Lab's inauguration, Dr. Clifford Brown (visiting researcher from Wittenberg University) had finalized the TRACE paradigm addressing design tradeoff negotiaticns (cf. Brown, Selvaraj, Whitaker, and McNeese (in press)), and Dr. Maryalice Citera (AFOSR-sponsored visiting researcher from Wright State University) was developing the AutoMate paradigm addressing design information sharing. Additional frameworks previously employed by the authors and readily available for CDT usage included the TRAP experimental paradigm previously used in studying multi-operator collaborative activities (Brown and Leupp, 1985) and the Jasper paradigm developed to address situated problem solving (McNeese, 1993).

TRACE

Effective design requires design decisions integrating relevant information from a variety of sources (Boff, 1987). Complex system design entails negotiation among parties pursuing common goals with potentially divergent interests and objectives (Bucciarelli, 1988). In multidisciplinary design teams, these parties negotiate from perspectives biased by their respective backgrounds, expertise, and roles. By impeding effective communication and preventing open, fully-informed consideration of design issues, these disjunct outlooks effect "cross-disciplinary chokepoints" (e.g., unawareness of or blindness to relevant technical data -- Boff, 1987). These chokepoints are problematic even for the relatively straightforward case of assessing tradeoffs

among a product's functions and attributes, which can be reduced to a dichotomous decision to include or exclude a specific feature (Cody, Rouse, and Boff, 1993). In a multidisciplinary setting, negotiating such inclusion becomes contingent upon effectively communicating one's own criteria, effectively assimilating others' criteria, and effectively cooperating to arrive at a mutually advantageous solution.

As part of our larger research effort in Collaborative Design Technology, we have examined the processes by which integrative design tradeoffs are realized, in preparation for enhancing these processes through data visualization and communication tools facilitating mutual understanding and consensual decision making. Integrative bargaining research in social psychology has systematically explored development of mutually advantageous outcomes in bilateral negotiation, typically using students role-playing buyers and sellers (Pruitt and Lewis, 1975). In order to explore the applicability of this research to multidisciplinary design, we constructed an integrative bargaining paradigm (TRACE -- Tradeoffs, Research, and Analysis in Collaborative Ergonomics) framed with respect to design tradeoffs in the development of an automobile navigation system (Citera and Selvaraj, 1992; McNeese, et al., 1993).

Because of our role as a human factors laboratory supporting U.S. Air Force operations, we emphasize *ecological validity* (Brunswik, 1956) in our experimentation. This raises the question of how to assess our contrived research paradigm's validity with respect to real-world design -- a research issue in itself. We hypothesized that if the paradigm reasonably captures the context of real-world multidisciplinary design practice, good task performance should be demonstrably proportional to actual design experience. Our experimental results support this hypothesis. More detailed descriptions of both the TRACE paradigm and results of its employment to date can be found in Brown, Selvaraj, Zaff, McNeese, and Whitaker (1994) and Brown, Selvaraj, Whitaker, and McNeese (in press).

<u>AutoMate</u>

AutoMate is a research paradigm devised to provide a framework for experimentally studying collaboration in multidisciplinary design. The paradigm was specifically crafted to address concurrent engineering's problems with *miscommunication*, *miscoordination*, and *misanalogies*, to the extent they derive from suboptimal information sharing. When design is conducted in a team setting, the mass of available relevant knowledge is distributed among a potentially wide population. When this population spans a variety of disciplines, the form of this knowledge may be "distributed" among a similar variety of jargons, models, background assumptions, etc. Owing to their diverse backgrounds, training, and professional practices, team members may effectively appear to speak different languages (Boff, 1987). The resultant misunderstandings and misinterpretations constitute *miscommunications.*

In addition, multidisciplinary team members may work on different schedules and be separated by physical distances. These factors may impede not only the actual design workflow (e.g., discussions, decisionmaking, and actions), but also the coordination of the workflow. Anyone who has played telephone tag understands the frustration of being unable to locate another team member. Such *miscoordination* may result in team members (e.g.) failing to fully inform each other, making decisions based on incomplete information, and generally wasting their time and effort.

Furthermore, designers often rely on a case-based strategy (Gero, 1990; Klein, 1987) -- approaching the current design problem by drawing analogies from past designs instead of generating and carefully evaluating all possible current alternatives. The advantage of a case-based approach is that good features from previous designs can be readily incorporated into the new project. On the other hand, if components of an earlier design are spuriously considered essential for -- and included in -- the current case, their unwarranted inclusion may restrict the design

options considered. When previous learning is applied to a situation where it may be inappropriate or conflict with other aspects of the design, *misanalogies* occur. Because misanalogies are difficult to articulate, they add to the communication problems multidisciplinary design teams face.

Team members must rely on both their own unique information and that of other team members to inform and guide themselves throughout the design process. Unfortunately, multidisciplinary design teams do not effectively share distributed knowledge. According to Stasser (1992); Stasser and Titus, 1985; 1987), groups often focus on shared information and neglect to discuss unique or unshared information. This may be because (e.g.) members of the team do not share an effective common framework within which design knowledge can be conveyed (miscommunication), cannot effectively transfer their data or otherwise pursue the design activity (miscoordination), or cannot relate the data to the problem at hand (misanalogy). In order to study these aspects of information sharing, the AutoMate task was created.

Based on Stasser's (1992) hidden profile paradigm, AutoMate requires subjects to consider the design of an automobile navigation display. Each subject receives a body of relevant data (the shared information) as well as a guidebook and design rationale which are specific to his/her own disciplinary role (the unique information). The construction of the specific design scenarios and the information packages relevant to them have represented the primary challenges in developing AutoMate. By manipulating the specific conditions for an automobile navigation design exercise as well as the distribution of information necessary to its accomplishment, AutoMate provides a realistic task framework within which patterns and degrees of information sharing can be tracked. Information sharing can be assessed in terms of (1) how much of the shared information is applied and (2) how much of the unique information is presented, shared, and incorporated in the final outcome.

The design domain for the AutoMate task -- automobile navigation displays -- is based on actual technical data and experiences obtained in part from design professionals (cf. the ASC Collaboration Study described elsewhere in this report). This affords the task a measure of *ecological validity* (Brunswik, 1956). Because the automobile navigation design domain is the same one used in the TRACE experimental paradigm, we have ensured some degree of uniformity across the tasks. The CDT-sponsored work toward developing the AutoMate paradigm is discussed in more detail in Citera and Selvaraj (1992), Citera *et al.* (1993), and the companion technical report (Citera, Selvaraj, McNeese, Brown, & Zaff, in press).

CDT Lab Observational Studies

Both applied and basic research efforts in the CSCW field have increasingly turned toward *ethnography*, *ethnomethodology*, *qualitative research*, and other methods emphasizing researchers' observations of collaboration *in situ* and a suspension of theoretical framing pending the collection of extensive empirical data. Related terminology includes: *grounded theory*, *case studies*, *conversational analysis*, *discourse analysis*, and *action research.* Weick (1984) concisely summarized such approaches under the label *intensive research,* based on the intensive study of relatively few subjects (as opposed to a narrowly-focused study of many subjects). Such studies typically provide valuable data for framing research issues and specifications for development (e.g., Reder & Schwab, 1988; 1990). Ethnography derives from anthropological field techniques which avoid reliance on quantitative data collection in favor of "...a commitment to a period and degree of immersion in the social setting being studied that is sufficient to reach a qualitative understanding of what happens there." (Shapiro, 1994, p. 418). The subset of ethnography most prevalent in CSCW research is *ethnomethodology*, initially formulated by Garfinkel (e.g., 1967) and popularized in IT circles by the work of Lucy Suchman (e.g, 1987). Ethnomethodology is rigorously empirical in the sense that it prioritizes comprehensive data collection as the prologue to analysis and theory building, in contrast to the theory-driven nature of other qualitative approaches.

The most tangible motivation for pursuing ethnography in groupware design is the explicit intent and widespread acknowledgement that distributed, communicative technologies intervene in workplace collaboration (as opposed to simply intervening in individual functions or operations). As such, these technologies' deployment affects the interpersonal or social aspects as well as the inter-role or functional aspects of work. These social aspects of work can only be assessed on their own terms, because they lie outside the scope of conventional (functionalist) requirements capture and analysis. Overlooking such social aspects of collaboration has been cited as the recurrent critical factor in groupware implementation failures to date (Grudin, 1988; 1990a; 1990b).

This does not mean that ethnography is easily applied to systems design. The leading practitioners of ethnography in design, Hughes *et al.* (1994), cite three major problems in transitioning ethnographic methods from their academic research origins into workaday applications. First, ethnographic methods work best for relatively small and distinct groups. In moving to larger and / or less well-delineated groups (e.g., hundreds of workers in a project organization), one runs into *problems of scale.* Second, ethnographic studies in the social sciences are typically of long duration -- sometimes lasting years. This time-intensive nature may apply to both the observational and the analytical phases of ethnographic research. In moving to more time-constrained or deadline-driven settings (e.g., systems design projects), one runs into *problems of time pressure.* Finally, ethnographic studies in the social sciences are typically descriptive academic exercises whose conduct and analyses are relatively non-threatening to the observed subjects. In moving to commercial and other development settings, access to and description of the subject activities become more problematic due to (e.g.) proprietary constraints, ethical considerations, and fear of negative feedback. In other words, there are *problems of the ethnographer's role.*

Ethnography's emphasis on studying work within its workplace context related to the concern for *ecological validity* CDT Lab inherited from the earlier AKADAM efforts (cf. McNeese *et al.*, 1993). The term "ecological validity" was coined by the ecological psychologist Egon Brunswik (1956) to denote the degree to which an experimental scenario corresponded to the actual or "natural" setting for the phenomenon or behavior being tested. In contrast to experimental approaches to studying group processes in collaborative design, CDT Lab observational studies emphasized direct field observations of design team members engaged in design meetings.

The near-term goal of the CDT observational studies was to explore and assess ethnographic practices for their applicability in systems design. The long-term goal of this approach was to examine the conduct of real-world design collaboration to identify factors relevant to effective configuration of support tools (e.g., information technology). The method was to collect background (e.g., documentation) and situational data (e.g., minutes of meetings) in preparation for analysis. In our efforts directed at the long-term goal, these observations were augmented by elicitation of design team members' experiences in design collaboration (both the observed meetings and other collaborations). Our observational studies could be characterized as concentrating on the Collaborative Design (CD) leg of the "CDT Triangle."

In the following sections, we will present and discuss two CDT Lab observational studies. The first -- involving the CCCD Field Demo 2 -- was aimed at our near-term goal of evaluating ethnographic methods. It emphasized CDTeam observation of a design team within its working context. The second -- involving the AutoMate studies -- was more directed at the long-term goal of identifying factors relevant to IT support for systems design. It emphasized structured interviewing surveying the experiences of designers with actual experience on a specific design task.

CCCD Field Demo 2

Introduction and background. In May 1994, the CDT Laboratory proposed an observational study involving the Crew-Centered Cockpit Design (CCCD) Laboratory in Armstrong Laboratory's Human Engineering Division. The goals of this study were:

(1) To familiarize CDT Lab personnel with ethnographic methods.
(2) To assess the application of ethnographic methods in a systems design setting.
(3) To assess the practicality of a large-scale ethnographic study of either the CCCD or a similar design team.

The CCCD Laboratory was in the process of conducting validation studies of its structured methodology and tools for re-designing aircraft crewstations. The CCCD methods emphasized rapid prototyping and hands-on simulation of the crewstation(s) of interest. As of June 1994, CCCD project personnel were beginning the second of their *Field Demo's* (validation studies), the subject of which was the re-design of the A/C 130 gunship navigation and fire control workstations. A multidisciplinary design team consisting of software and hardware engineers, human factors specialists, subject matter experts, and program managers was involved in the summer 1994 validation effort (hereafter termed *Field Demo* 2) -- making it ecologically valid with respect to USAF systems (re-)design generally. The involvement of actual flight crew members as subject matter experts (SME's) and participants in the simulation runs afforded reasonable ecological validity with respect to the particular system of concern.

We had determined that any design project targeted for our initial ethnographic data collection should be short-termed and highly focused, so that immersion into the design setting was both operationally feasible and conducive to substantive data collection. The CCCD Field Demo 2 had an expected duration of approximately 3 months and was concentrated on the evaluation and re-design of two aircraft crewstations. These factors, in our opinion, satisfied our general criteria.

In a full-scale ethnographic study, it would have been the CDTeam's goal to immerse itself in the daily activities of a working design team and collect data via (e.g.) direct observations, activity logs, video records, and audio recordings. This was the general plan offered by CDTeam in its initial meetings with CCCD staff and government monitors. However, not all the facets of this suggested plan were implemented, due to concerns voiced by both CCCD staff and CDTeam. The prospect of being the subjects of extensive field observations immediately raised a number of questions on the part of the CCCD personnel. Some of the issues raised included: confidentiality of observational data; degree of CDTeam access to potentially proprietary information; logistics of CDTeam access to the CCCD project site; logistics of CDTeam access to Field Demo 2 activities; and logistics of CDTeam access to participating personnel. In parallel, CDTeam began to question the feasibility of full-blown ethnographic data collection in the course of this initial exercise. The Field Demo 2 work would proceed daily and involve approximately a dozen on-site personnel. Comprehensive video and/or audio records of the design work would require equipment and media stock representing a potentially excessive investment.

In the end, CDTeam's negotiations with the CCCD project staff resulted in a data collection plan which generally limited CDTeam access to the project status meetings held (on a weekly basis) during Field Demo 2. Video recording was ruled out, and audio recordings of even these status meetings were not permitted at first. After further negotiation, the CDTeam was permitted to make audio recordings beginning with the meeting of 22 June 1994 and continuing throughout the remainder of our Field Demo 2 observations. In addition to the status meetings, CDTeam monitored: the design of data collection methods for evaluating the workstation redesign (15JUL94), a two-day Cockpit Working Group (CWG) meeting in which subject matter experts (SME's) evaluated prospective design changes (26JUL94 / 27JUL94), the CCCD outbriefing for government monitors and SME's (01SEP94), and the CCCD project staff's review of change

proposals generated during the Field Demo (07SEP94). In summary, the Field Demo 2 meetings we monitored were as follows:

17MAY94	Introductory Meeting with CCCD Contractor and Government Personnel
01JUN94	Project Status Meeting
07JUN94	Project Status Meeting
09JUN94	Project Status Meeting
16JUN94	Project Status Meeting
22JUN94	Project Status Meeting
29JUN94	CDTeam Interim Meeting with CCCD Management (background data)
07JUL94	Project Status Meeting
15JUL94	Meeting to Design Data Collection
26JUL94	Cockpit Working Group Meeting, Part I
27JUL94	Cockpit Working Group Meeting, Part II
03AUG94	Briefing to CCCD Design Team on Observations
16AUG94	Project Status Meeting
24AUG94	Project Status Meeting
31AUG94	Observations of Field Demo 2 Simulation Runs / Data Collection
01SEP94	Outbriefing
07SEP94	Change Proposal Review Meeting

These meetings covered the progress of Field Demo 2 from its inception through to its conclusion with an outbriefing with the SME's and a review of proposed changes to the CCCD methodology and tools. In terms of the general temporal extent of observational coverage, CDTeam obtained adequate access to the CCCD Field Demo 2. In terms of the "depth" of observational coverage, CDTeam's monitoring of Field Demo 2 would not have been sufficient for a full-blown ethnographic study. However, for the stated purposes of this exercise (familiarization with and assessment of ethnographic practices), the relatively "shallow" data collection program negotiated with CCCD staff was sufficient.

For each of the listed meetings, one or more CDTeam observers were present. The maximum number of CDTeam observers in attendance was four, and two was typical for most of the meetings. The main method of data collection was writing notes, augmented starting 22 June 1994 with audio taping using a portable cassette recorder. The weekly status meetings varied from 30 to 90 minutes in length, the outbriefing lasted 2 hours, and the CWG meetings spanned 2 days. After each meeting, the observers would return to CDT Lab to collate their written notes and transcribe them via word processor into computer files, which were then collected and collated by a designated lead observer. CDTeam observers would often compare notes for clarification during this transcription period.

The following sections summarize the results and lessons learned assoociated with our evaluation of the CCCD field demo 2.

Ethnographic studies require a great deal of background preparation. A real-world design team works toward its own goals on its own terms. In contrast with experimental settings wherein all but the issues and factors of research interest have been referentially neutralized, observers of actual workplace practice must be prepared to interpret their subjects in a more complex and less regularized setting. Much of this complexity can be attributed to situational factors -- i.e., characteristics of the work which are specific to the particular setting. In highly technical settings such as systems design, situation-specific factors such as terminology, documentation, history of prior decisions, local codes of practice, and the results of circumstantial responses contribute to this complexity. We found this to be the case in Field Demo 2.

The CCCD design team provided the CDTeam with a considerable amount of written material

(conference papers, weekly activity reports, and technical reports), which were collated and reviewed as background material in support of the observational study. This material proved critical in facilitating our ability to track and interpret the observed meetings, owing to the design team's reliance on the CCCD structured "map" for the Field Demo process and the relatively large amount of CCCD-specific terminology employed. One illustration of this issue's importance was that much of the interim meeting with CCCD staff management (29JUN94) concentrated on CDTeam's confirming interpretations of CCCD-specific items.

Ethnographic studies entail considerable expense for data collection. As noted earlier, one of the reasons for scaling down the Field Demo 2 exercise from the initial suggestion of a full-blown ethnographic effort was the cost for equipment and media stock requisite to simply recording the design activities. The fact that we determined the projected costs were exorbitant for this familiarization exercise does not imply that they are automatically manageable for full-scale studies. Labor costs for observation are directly proportional to the number of observers per session and the duration of the sessions observed. Based on our typical practice, total coverage of Field Demo 2 would have entailed a minimum of 2 CDTeam observers over the entire 3-month period -- a total of 0.5 person-years and approximately 15-20% of the person-years invested by the Field Demo 2 team itself in conducting their work.

Ethnographic studies entail considerable expense for data collation. The simple transcription of observer notes into electronic files with a word processor consistently took at least twice the amount of time taken up by the meeting in which the notes were made. For individual observers transcribing their own notes, the minimum *transcription ratio* (ratio of transcription time-to-observation time) we noted was approximately 1.5:1, and the maximum noted was approximately 5:1. We attempted to streamline this process by having multiple observers cooperatively compile and transcribe all the notes from a meeting. The result was a marked degradation in the transcription ratio. In one instance the collaborating transcribers were the CDTeam's fastest on an individual basis (consistently 2:1 or better), but managed only about a 4:1 transcription ratio working jointly. For both individual and joint transcriptions, we found that much time ended up being invested in interpreting raw meeting notes (one's own or someone else's), clarifying points by consultation with others, and "fleshing out" the resultant text. Trial attempts to augment transcription with the audio tapes did not result in a noticeable improvement in the transcription ratio. As a result, the audio tapes remained relegated to a backup role, providing a comprehensive reference of last resort on those occasions where individuals' notes were contradictory or incomplete.

Ethnographic studies entail a reversal of relative procedural control between researcher and subject(s). In an experimental setting, researchers control the scheduling and duration of sessions, making their time and resource allocation relatively easy. In ethnographic studies with total observational coverage, researchers are obligated to be on hand wherever and whenever the subjects are active. This means that ethnographic researchers are at the mercy of the subjects' scheduling constraints, breakdowns, and other coordination problems. In addition to the obvious potential for inconvenience, this can affect researchers' ability to manage their (typically constrained) research resources. Unexpected changes on the part of the observed can induce increases in the above-mentioned costs which, combined with increased overhead for providing observational coverage itself (e.g., transportation), can be detrimental to observers' control over their time, equipment, and fiscal budgets. This reversal of relative control suggests itself as one explanation for the frustration occasionally felt by some CDTeam personnel during the course of their first ethnographic experience. It also highlights the need to provide for the unexpected in planning an ethnographic study, particularly if total observational coverage is desired.

Ethnographic data collection can vary with observer capacities. In discussing the transcription ratio earlier, we noted some variation among CDTeam observers' efficiency. We found during the course of this exercise that there were also variations in their note-taking. Specific dimensions of

consistent variation among CDTeam observers included: degree of detail; attribution of comments to speakers; granularity of observations (e.g., "blow-by-blow" vs. "summary points"); volume of note documentation; usage / misusage of relevant references (e.g., to CCCD-specific terminology); degree of observer "interpretation" from actual subject utterances; time tracking; and subject attendance tracking. These variations were largely responsible for the fact (mentioned earlier) that collaborating observers consistently found collaborative transcription slower (and more frustrating) than individual transcription.

To summarize these specific points, we believe that ethnographic studies must be planned with sufficient attention to realistic time and resource assessments. Our initial ethnographic exercise did not push farther on to review and analysis, each of which will unavoidably raise the researchers' costs for this type of enquiry. Our experience is that the conduct of such studies is expensive in terms of invested time and incapable of precise schedule management. We suggest that future such studies could address these problems through either scaling down their degree of observational coverage, scaling down the number of observers employed, or delegating much of the direct observation duties to lower-cost personnel (e.g., junior staff or temporaries).

We believe that the transcription ratio might conceivably be reduced in practice to around 1:1, but that this is not likely unless observers' field notes are more directly convertible into their archived format. One obvious solution would be to reduce the transcription ratio to 0:1 -- i.e., eliminate the need for post-session transcriptions. Specific means for accomplishing this include the use of portable computers or personal digital assistants (PDA's -- e.g., the Apple Newton™) by observers on-site. Another approach which might prove cost-effective in some cases would be the employment of proficient professionals drawn from other work settings (e.g., stenographers).

We suggest that the problems of situational complexity could be reasonably addressed through advance familiarization with the subject scenario. The problem of inter-observer variation is not so easily addressed. One could attempt to address this by employing a structured protocol for capturing specific events or content, but this could readily degrade the richness of data in an ethnographic approach generally and disqualify a study from meeting the criteria for an ethnomethodological approach specifically. Nonetheless, such a "mixed-mode" tactic might well be necessary to approximate the penultimate ecological validity of an ethnographic approach within typical operational constraints. Certainly inter-observer variation could be partially reduced through effective and uniform training, but we doubt this is a guaranteed cure. The most effective solution would be attention to selection of individual observers. In our (admittedly limited) experience, the main sources of variation were frankly personal -- e.g., individual skills in listening, notetaking, transcription, and interpretation. Within our (admittedly small) population of observers, relative proficiency in these skills did not apparently correlate with professional specialization or experience in other modes of studying human behavior.

Speaking generally, we find the results of this ethnographic exercise to have been entirely consistent with the issues identified by Hughes *et al.* (1994), discussed earlier. Our evidence from burdened schedules and transcription ratios demonstrates the "problems of time pressure," at least insofar as they pertain to the ethnographers' own work. Even though the CCCD design team and Field Demo 2 were of presumably tractable size, our assigned resources were taxed during this study. We are convinced that had the subject population been larger or the project timeframe longer, we would have encountered "problems of scale." Finally, our experience provides compelling evidence for those authors' concern with "problems of the ethnographer's role." By this we mean that in certain instances significant energy had to be devoted to resolving issues of the study's conduct (as opposed to the study's content). In this case, such issues included:

• Permission to obtain access to the CCCD Field Demo 2 activities
• The extent and frequency of CDTeam observations
• The types of activity CDTeam could observe

• The "ground rules" for CDTeam observational activity
• The type(s) of data collection (e.g., audio tapes) which could be employed
• The type(s) and amount of background documentation to be delivered to CDTeam
• CDTeam familiarization with the background (e.g., jargon, tools) to the subject activity
• Scheduling and coordination of CDTeam observation
• CDTeam feedback on the subject team's work
• Potential CDTeam contribution to the Field Demo 2 Validation Test Plan documentation

We are not claiming that there were untoward obstacles in addressing these issues, nor are we inferring that our relations with the CCCD project and its personnel were anything but benign. We are simply affirming the common wisdom in ethnographic and qualitative research that an unexpectedly large proportion of researchers' overall project time will be spent on such "procedural" matters. This means that: (1) significant "ramp-up" time should be budgeted for advance negotiations in any ethnographic study; (2) good relations with the subjects are of primary (and not peripheral) importance; and (3) researchers should budget significant time resources (with regard to procedural matters) above and beyond those required for the observations and analyses themselves.

The foregoing affirmation of the burdens entailed in ethnographic research does not mean that we believe the approach to be something best avoided. In the course of this study, we repeatedly observed interactions involving (e.g.) negotiations of design tradeoffs which set the context for the eventual crewstation redesign. The extent to which such tradeoffs were recognized and the grounds upon which they were resolved were not evident in the final crewstation prototypes themselves. We developed an appreciation for the extent to which the explanation for a final product lies in the historicality of its design process and not necessarily in deterministic decision making on predictable technical or functional issues. This observational study affirmed the criticality of design rationale as a factor steering the course of design and as a form of data which is generally useful as documentation and specifically valuable in direct proportion to the complexity of the design project and its product(s).

Based on our experience, we believe that unless and until tools for real-time accretion of design rationale mature, ethnographic techniques provide a viable means for documenting this critical background data. Consideration of an ethnographic approach must include attention to the diverse costs well-documented in the relevant literature and affirmed by our trial experience. Selection and training of ethnographers should be carefully planned and carried out. Above all, planners must recognize the relatively "all or nothing" nature of such research work. Because ethnography's payoffs are predicated on the comprehensivity of data collected, its success requires a commitment to sustained and comprehensive observation.

ASC Collaboration Study

In discussing Concurrent Engineering and Integrated Product Design, we cited the work with the USAF's Aeronautical Systems Center (ASC) reported in McNeese *et al.* (1993). That study elicited knowledge from ASC human factors specialists concerning (e.g.) design teams' organization, interpersonal relationships, generalizable experiences, and resolution of design problems. Since the publication of the 1993 paper, this data has been subsequently analyzed to identify and compile tips, clues, and issues pertinent to how information technology can be best configured to constructively support real-world design teams. The detailed report on this study can be found in Citera, Selvaraj, McNeese, Brown, & Zaff. (in press). The primary issues identified are summarized in the following points:

1. *Design rationale is important, but problematical.* The ASC experts reported that past experiences were often the bases for critical design decisions and the justification for resolving tradeoffs, even though the credibility of such experiential data is not easily assessed. Personal

differences in experience were claimed to underlie perceived differentials in participants' credibility, thus affecting the social dimension of multidisciplinary design. Design rationale data should include its source, but this entails possible problems with accountability or attribution.

2. *Information sharing is critical in multidisciplinary design teams.* The ASC experts stated that differences in jargon and conceptual frameworks are very problematical for multidisciplinary design teams. This affirms Boff's (1987) concern for such teams working under conditions equivalent to a "Tower of Babel." The ASC experts suggested that effective tools for compiling common working lexicons and indexing shared data resources are much needed. This result affirms the importance of a common medium of expression -- the "shared information space" Robinson (1991) cites as one of CSCW's most critical conceptual contributions.

3. *Joint decision criteria are critical in multidisciplinary design teams.* Data analyses, risk assessments, and the like are complicated enough without having to deal with multiple disparate frames of reference. Above and beyond a "shared language" for depicting design tradeoffs, multidisciplinary design teams must arrive at a consensus regarding the justification for decisions on those tradeoffs. This result affirms the problems with "different ontologies" in multidisciplinary design discussed by Bannon and Robinson (1991), and it cautions against the reification of simplistic decisionmaking presumptions in groupware artifacts, such as those identified for group decision support systems (GDSS) by Whitaker (1994).

4. *Designers need lateral access to experts and colleagues.* The ASC specialists noted the importance of obtaining information and opinions from people outside the multidisciplinary design team itself -- e.g., from technical experts. Means for supporting this function include communications systems supporting conferencing (e.g., Usenet news groups) and repositories for design expertise. This affirms the need for good communications in both the technical and professional senses.

5. *Facilitating productivity and effectiveness of design meetings is a priority.* In accordance with the literature on concurrent engineering, the ASC experts noted that multidisciplinary design entails many meetings. Tools and procedures enhancing meeting focus, agenda formulation, time usage, and distribution of outcomes would be very beneficial. This affirms the CSCW emphasis on tools for group decision support.

To summarize, the ASC Collaboration Study produced concrete affirmation for many of the concerns represented in CSCW research generally and the CDTeam agenda specifically.

CDT Lab Simulation Studies

During our research planning, we identified a third class of research activities which did not readily fall under either the categories of experimental or observational studies as described earlier. These activities were those which derived from that element of the August 1993 mission statement mandating us to "...model and simulate advanced groupware to assess human and technology demands and implementation feasibilities." This entailed setting up and conducting interaction between users and available collaborative technologies, toward evaluating the human and other operant factors at work. We termed such activities *simulation studies*, based on the idea of their entailing "simulations" of workplace activity supported by innovative technologies. With respect to the CDT Lab (and its equipment) as a reconfigurable testbed, we envisioned simulation studies to proceed recursively as follows:

- Study design teams in the Group Interface Facility testbed
- Analyze design teams' usage of the Group Interface technologies
- Apply the results of such analyses to evolve the Group Interface Facility

Such simulation studies were most commonly a test of one or another feature within the framework of a real-world group activity. Many of the CDTeam's simulation studies were conducted in conjunction with the provision of knowledge elicitation and facilitation services to local (USAF and associated contractor) clients. These services typically relied on the concept mapping techniques developed in the earlier AKADAM work (McNeese *et al.*, in press). CDTeam's facility in such activities allowed us the ability to study clients' behavior in the course of activities involving the use of IT (e.g., software, large display devices). Such work was aimed at identifying human factors issues relevant to group IT usage. One such issue we studied was the interaction between collaborators and their shared information spaces. In the context of CDTeam-facilitated sessions, this interaction was between clients and the representations they jointly constructed.

Depictional Lock-On: An Instance of Flipover

Access to a common medium for collective activity is one of the fundamental elements in CSCW. Bannon and Schmidt (1989, p. 364) identify "sharing an information space" as a "core issue for CSCW," De Michelis (1990) cites "information sharing" as the key support for collaborative activity, and Robinson (1991) cites *shared information space* as one of the most important "CSCW specific concepts." Both Robinson (1991) and Bannon (1991b) credit Thompson (1984) with this concept, which is implicit in Engelbart's seminal visions of shared IT applications (cf. 1963; 1982) and (termed *shared environment*) Ellis *et al.*'s (1991, p. 40) definition for "groupware." This section will describe an enquiry into human factors issues surrounding team members' relative degree of attention to their shared information spaces (as opposed to each other) during collaboration. This topical focus is best framed with regard to two theoretical models from the CSCW literature.

Robinson (1989; 1991) differentiates between two modes of group interactivity which he characterizes as "levels of language." The *formal level* consists of structured modes of interactivity, usually guided by the model or rules embodied in (e.g.) a software application. This level "...is essential as it provides a common reference point for participants ... a sort of 'external world' that can be pointed at, and whose behavior is rule governed and predictable" (1989, p. 56). The *cultural level* denotes "...a language that is actually spoken by a community of people." Conversations at the cultural level may involve "...understanding, interpreting, and changing 'items' at the formal level... ," "...procedural and annotative activities... ," and "...also any other social or interpersonal aspects (relevant to the 'problem' or not) that the participants wished to introduce." (Ibid.).

In a similar vein, Whitaker (1992) outlines a *venue framework* for analyzing IT-supported collaboration, employing the legal sense of "venue" (jurisdiction) to connote a setting or circumscriptive medium for action. The framework derives from Maturana and Varela's (1980) concept of *phenomenological domain* -- a realm of action defined by the individual properties of its constituents and their collective transformations or interactions. Accordingly, electing one of the venues focuses attention on the entities and actions constituting it, thus specifying a vantage point for analysis. Two of these venues will be employed for the purposes of this discussion. The *depictive venue* is the "informational" context -- the composite set of all symbolizable data available to the decision maker. As a target, it is the composite set of all symbolizable data generated during the decision making process. The technological interventions effected by groupware (e.g., shared data capacities) are typically realized in this depictive venue. The *discursive venue* is the communicational setting subsuming all direct interactivity in a meeting, i.e., the overt activity linking participants to each other. The interactional interventions effected by structured procedures are primarily realized in this discursive venue.

These two taxonomic models address similar issues, but they are not necessarily isomorphic. Robinson's distinction of formal versus cultural level language hinges on the degree of

structuration in communicative activity. Whitaker's distinction of depictive versus discursive venues hinges on a differentiation of settings or media in which communicative activity is conducted. We will need to invoke both models in delineating the relative interplay of natural conversation (cultural level language / discursive venue) and structured representational schemata (formal level language / depictive venue) in collaborative IT usage.

Our interest lay in exploring the operational confluence of the depictive and discursive venues, to the (typically substantial) extent that participants may address each other (discursive venue) only through the mediate textual data space (depictive venue). More specifically, we wished to explore what Robinson and Bannon (1991) term *flipover* -- the phenomenon in which "...the object of an interpretation and the interpretation itself change places." (p. 225, emphasis in the original). They provide multiple examples characterizing flipover in terms of a mutually created interpretive unity (e.g., a position, a document) becoming a fixed object subject to later interpretation. Flipover is thus characterized as an unavoidable phenomenon in interaction (therefore in group work). On the other hand, flipover, as a "...dialectical movement between an object of interpretation and interpretation itself..." (Bannon & Robinson, 1991, p. 223) imparts utility and power to collaboration.

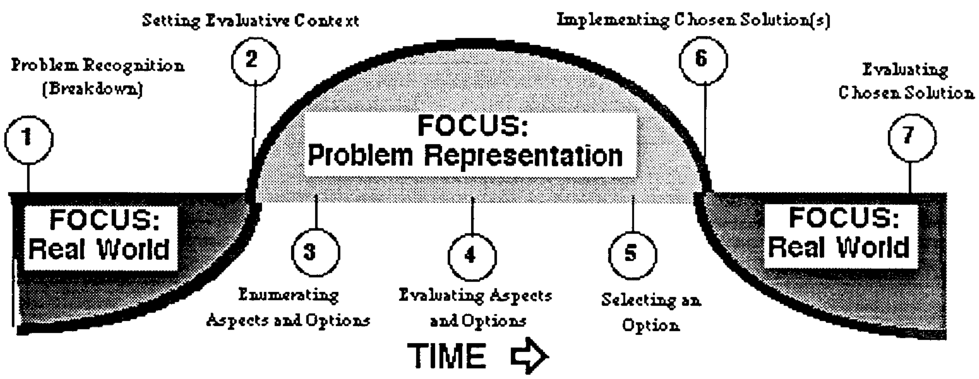

Figure 4. Model for problem solving

Now let us illustrate the relevance of the concepts of flipover, formal / cultural level languages, and discursive / depictive venues in framing human factors issues of IT-supported design collaboration. Whitaker's (1992; 1994) model for problem solving (illustrated in Figure 4) applies to design decision making generally. In the course of taking steps toward problem resolution (steps 1-6 in the figure), problem solvers typically shift from consideration of their real world issues to one or more representations (e.g., rough sketches). Once those representations have been manipulated to the point of framing a solution (e.g., a finished design drawing), the focus shifts back to the real world to effect implementation. The first transition (cf. Step 2 in the figure) corresponds to a flipover, a shift from cultural to formal level language, and a shift of emphasis to the depictive venue. This point is the critical locus at which insufficiencies in problem recognition become reified in working models and the attendant costs of subsequent correction grow dramatically.

Observations of CDTeam client interactional behavior within the structured setting of our facilitated services revealed that shifts of relative focus between the natural conversational space and the emerging structured representations (e.g., concept maps, graphs, lists) did in fact occur. For example, it was common for clients to initiate a knowledge elicitation session by conversing with their fellows or with the facilitator(s) without significant conversation being directed toward the tools or representational devices themselves. During the course of many such sessions, we

noticed a progressive shift in conversational indexicality (direction or focus of discursive reference) from the task or issue under discussion per se to the emerging representational product. In other words, as meetings went on, we noted that participants talked less in terms of the subject matter and more in terms of the emergent representations of that subject matter. In some cases, this shift was so pronounced that clients were framing their comments almost wholly in terms of components of the representational schemata (as opposed to features of the issue under discussion).

Our earliest observation of this shift occurred in July 1993, during a concept mapping session with a single subject matter expert (SME) in the AL/CFH MultiMedia Room -- a computer-supported presentation and meeting facility. The primary concept mapper employed Inspiration™ software on an Apple Macintosh™ computer as the mapping medium. The SME observed the emerging representation on a large rear-projection video display at the front of the room. As the SME talked about the subject of interest (plans for a joint services equipment evaluation program) the mapper, using keyboard and mouse, generated nodes and links corresponding to the major points. Five other CDTeam members were seated to the side, and they only occasionally entered into conversation with the SME and / or the mapper. One of these CDTeam members observed the interaction between the SME and the others, noting any instance where the SME spoke with reference to the concept mapping rather than with strict regard to the subject matter (e.g, the equipment of interest or the proposed evaluation effort). The data collection method was handwritten notes, which were then transcribed into an electronic file and categorized topically.

To use Robinson's terminology, the formal level language consisted of the node-and-link concept mapping representation. The SME was advised prior to the meeting that he would control the session's discourse, so the conversation between the SME and the mapper was not "formal level" -- at least not initially. The cultural level language was simply the natural conversation of the SME and the mapper. To use Whitaker's terminology, the discursive venue was comprised of the meeting room space, the participants, natural language and the other behaviors (e.g., gestures) comprising the interpersonal communication between SME and mapper. The depictive venue consisted of the computer, its control interface, and the large common display onto which the concept map was projected.

During the two hours and forty-five minutes of this 1993 session, the SME progressively shifted from talking about his program planning to directing the construction and reconfiguration of the concept map on the video display. Phrased another way, his primary style of interaction with the mapper shifted from dictation (speaking for the record) to direction (telling how the record itself should be modified). During the first 10 minutes of the session, he sat comfortably back in his chair and directed his primary gaze at the mapper. By the time the first quarter hour was complete, he had come forward in his chair, leaned on the table before him, and directed his primary gaze at the video display. Whenever engaged in the concept mapping directly (as contrasted with side conversations), the SME consistently adopted this latter postural orientation throughout the remainder of the session.

A second shift occurred during this same period (10-15 minutes into the session). The SME began speaking with regard to the display and the concept map in his interactions with the mapper. Some aspects of the display-directedness were clearly related to the constrained physical affordances of the setting (e.g., limited display area). Examples of this included (1) directing the mapper to scroll the display image to bring a specific portion of the map into view and (2) commenting to the mapper on the display's size, clarity, and legibility. These references to the display were understandable responses to the circumstances within which the knowledge elicitation was occurring. More interestingly, the SME responded in a similar fashion with respect to the knowledge elicitation process itself. By this we mean that the SME progressively framed his conduct as an interviewee with reference to the representational device (the concept map) projected on the large display. Examples of this representation-directedness included:

- Directing the mapper to add one or more nodes extending from a specific point in the map (e.g., "Add a node off that one there.")
- Directing the mapper to delete nodes (usually empty ones left over from some previous manipulation)
- Asking to review some portion or the entirety of the map before continuing
- Directing the mapper to modify location of a node
- Directing the mapper to cluster or re-arrange sets of nodes
- Directing the mapper to change the entire text label for a node or for a relational link between nodes
- Directing the mapper to add explanatory text or terms to node or link labels
- Directing the mapper on color coding certain of the nodes
- Directing the mapper to change or correct spelling in the text labels for nodes or links

We found the same general effect in sessions involving multiple SME's or clients. In March 1994, CDTeam facilitated two planning sessions with a group of six government managers from a USAF research laboratory, each of two hours' duration. The goal of the meetings was to outline specific requirements for a large-scale systems integration project. The site was the CDT Lab meeting space, and the knowledge elicitation method was again concept mapping. The SME's were seated side-by-side (as a panel) before a wall of whiteboards, on which the single knowledge elicitor constructed a concept map. In parallel, another CDTeam member was transcribing the emerging map into an electronic version projected onto a six-foot-square screen located to the SME's left at a 45 degree angle. The actual point of this parallel activity was immediate transcription of the whiteboard map into electronic format for ready distribution at the session's end. The transcription copy was projected during the session as a convenience, providing additional display feedback to the SME's. Both sessions were videotaped from two camera angles (one facing the panel, one looking over the back of the panel toward the mapper and the whiteboards). CDTeam review of these videotapes was the method of analysis with respect to this particular issue.

As with the individual case described above, the SME panel members exhibited progressive shifts in postural orientation and gaze directedness with respect to the concept map being constructed. The point of noticeable shift occurred about 10 or 15 minutes into the session. The consistency and conclusivity of this shift was not so pronounced as for the individual case, apparently owing to occasional general crosstalk among the panel members and more specific rounds of crosstalk initiated in response to some particular point or question during the session. Similarly, these panel members exhibited the general shift "from dictation to direction" noted in the individual case. When making an initial point, each panel member progressively came to direct the course of the concept mapping rather than simply dictate a proposition. As for the orientational shift, the consistency of this conversational shift was less than in the individual case. As for the orientational shift, crosstalk (e.g., responding to a suggested point, adding items to a list initiated by someone else) was the apparent correlate to falling back into "dictation mode" with respect to the concept mapper.

In terms of specific instances where either prior propositions, novel referents (e.g., names, acronyms), or their representations became points of subsequent reference, the examples demonstrate the flipover phenomenon. Flipover pertains to the *meaning* of an emerging group product, as evidenced by Bannon and Robinson's (1991) allusion to the statement in Neuwirth *et al.* (1990, p. 185) that "...the partially completed product plays an important role in this process: The partially completed product becomes part of the task environment and constrains the subsequent course of the design..." In terms of Robinson's double level language, flipover occurs when cultural level language feeds forward to effect the regularization of a formal level language. Consistent with its definition in the literature, flipover is a theoretical model for an epistemological phenomenon discernible in terms of cognitive constructs (i.e., yet more theoretical models).

In contrast, the behavioral shifts we observed in attentional orientation and behavioral framing with respect to the facilitator / mapper concern subjects' orientation to the *depiction* of the emergent product in their shared information space. In other words, we observed shifts with respect to the "vehicle," as well as the "content," of the emergent information artifact (e.g., a concept map). To distinguish this effect from flipover, we term it *depictional lock-on.* In terms of Whitaker's venue framework, depictional lock-on marks the point at which communicative activity within the discursive venue becomes demonstrably coupled to manipulative conduct within the depictive venue. Depictional lock-on is a theoretical model for a behavioral phenomenon discernible in terms of concrete, potentially quantifiable, evidence (e.g., gaze directedness, conversational phrasing) of the sort amenable to human factors research.

Even though our observations of the depictional lock-on phenomenon were secondary to the sessions' goals and the data collection was ad hoc, there is consistency in the limited evidence to date. Whereas flipover is described as a continuously recursive process, depictional lock-on operates as a transition across a delineable boundary in the course of a collaborative session (e.g., 10-15 minutes into the example sessions above). In the example sessions described above, depictional lock-on typically dissipated or broke down when the subject(s) had to interact with others in the room -- i.e., when communicative activity within the discursive venue decoupled from the depictive venue. In the case of the group sessions, participants exhibited differential degrees of lock-on generally and during crosstalk. A striking example occurred in the first group session. One participant consistently faced a second addressed during crosstalk, but the addressee consistently responded verbally while gazing at the concept map -- even punctuating response comments with pointing gestures toward the whiteboards. The lock-on effect, after its initial appearance, could be re-established after a break with no discernible delay corresponding to the initiation period.

More suggestively, it was observed that the subject(s) in the example sessions above tended to phrase their statements regarding basic sufficiency and finality for the session in terms of the concept map representation rather than their perceived coverage of the subject matter. In the individual case, the SME stated "Now I have a concept map" at about 1 hour into the session, and the close of the session came when he (1) suggested the map was approaching comprehensivity (without reference to the subject matter) and then (2) stated that the map's evolution had reached a good stopping point. At the end of one of the group sessions, when the SME's were trying to specify the next step in their planning process, they discussed (1) taking the generated concept maps and showing them to higher management and (2) framed higher management's prospective feedback in terms of reaction to the concept maps themselves.

Production of a shared informational artifact is a focal scenario for CSCW research and the explicit goal of knowledge elicitation sessions such as the examples above. Sharing a medium of expression is one of the benefits claimed for groupware generally and the earlier AKADAM work specifically, predicated on the idea that a common mode of expression or depiction would counteract the "Tower of Babel" effect which bedevils multidisciplinary design teams (Boff, 1987). Identification of this problem and the suggestion of a shared medium as its solution are substantiated by the findings of the ASC Collaboration Study reported elsewhere in this report and in Citera, Selvaraj, McNeese, Brown, and Zaff (in press).

Before letting the issue rest with prescription of shared media, however, one must ask if any such "shared language" is necessarily an improvement and, if so, on what terms. Given the scope of this discussion, we shall address this in terms of the shared medium's influence over the course of constructive (e.g., text-producing) collaboration. Earlier, we noted flipover being defined when a "... partially completed product becomes part of the task environment and *constrains* the subsequent course of the design..." (Neuwirth *et al.,* 1990, p. 185, emphasis added). This is affirmed by empirical evidence that collaborative affordances are critical to usability of all shared

media and adoption of novel ones (Luff, Heath, & Greatbatch, 1992). Such ongoing constraint can be construed either as positive (progressive focus) or as negative (progressive tunnel vision). Let us consider both sides of this tradeoff in turn.

The positive payoffs of shared information have been accepted without question since the days of Engelbart's seminal work. Attention to the object of mutual construction is presumed to facilitate common understanding, provide a basis for error-checking, stimulate points for further development, and delineate the grounds for consensus building. We had in fact noted the occurrence of such effects in group concept mapping sessions (Zaff, Hughes, McNeese, Brown, & Citera, 1993). Focused attention on primary subject matter is a key aspect of that style of effective creativity termed *flow* (Csikszentmihalyi, 1990) -- the very sort of constructive activity we wish to facilitate in design. Illustrating the potentially negative side of flipover / depictional lock-on requires no more than extending the speech metaphor underlying the "Babel" problem statement and the prescribed "shared language" cure. This unavoidably brings one to the historical examples of shared language in collaboration -- the pidgin dialects generated to facilitate trade. Pidgin dialects are characterized by a limited lexicon and an extremely simplified grammatical structure. Bannon and Robinson (1991) defined flipover in the course of discussing the dangers of over-reliance upon models and representations in the design process. Our observations of flipover and depictional lock-on give us reason to question if there are tradeoffs to be considered between the benefits of shared media and the dangers of describing the complexities of large systems using the equivalent of a pidgin dialect.

The epistemological constraints of structured knowledge engineering schemata (including the semantic network model exemplified in concept mapping) were among the problems participatory practices such as AKADAM were created to alleviate (Zaff, McNeese, & Snyder, 1993). Achieving better design through collaborative technology entails, but may not stop with, making Collaborative Design practices user-centered. Our parallel interest in Collaborative Technology has led us to explore how shared information spaces (the depictive venue) interact with and affect the constructive process we call design. Our application of current CSCW theory in observing real collaborative tasks has given us clues to at least one human factors phenomenon (depictional lock-on) whose further study may inform effective shared expression.

CDT Lab Technology Studies

Groupware Evaluations

The basic CDT Lab IT infrastructure (described elsewhere in this report) provided us with some of the basic capacities for collaboration -- e.g., networking, email, and file sharing. Because AL/CFH migrated from a centralized to a distributed mode of internal networking during this reporting period, we also drew on our daily experiences with the Novell NetWare™-based LAN and WordPerfect Office™ (now marketed as Novell GroupWise™). In addition, we evaluated a variety of available software categorizable as groupware, collaboration support tools, and/or tools relevant to interfacing teams with computers. These software packages included:

- NCSA Telnet (TCP/IP communication software allowing desktop access to the Internet)
- NCSA Mosaic (HTML browser for the World Wide Web)
- NetScape (HTML browser for the World Wide Web)
- TurboGopher (Macintosh software enabling direct Gopher information service access)
- Aspects™ (Shared medium for textual and graphic manipulation)
- Co-Motion™ (Shared structured conferencing tool)
- ShareVision™ (Desktop video conferencing package for the Apple Macintosh™)
- MacHandwriter™ (Pen-based handwriting recognition package for the Apple Macintosh™)
- ShrEdit (Shared text editor software)
- Timbuktu (Software for sharing screen and control capacities between two computers)

• MacShapa™ (Software for exploratory sequential data analysis)
• TAKE (Concept mapping software for knowledge elicitation)
• Inspiration™ (Graphic software for knowledge elicitation and structuring)
• Collage (Collaborative data visualization)
• Euclid (Conferencing support)
• Mac Meeting Manager (Conferencing support)
• MacDiscuss (Conferencing support)
• Maven (Digital voice conferencing support)
• Meeting Maker (Conferencing support)
• Oval (Information management)
• PREP (Collaborative editing support)
• Town Meeting (Conferencing support)
• TalkShow™ (Screen sharing application for PCs running Windows™)

Of these various packages, we consistently found that a combination of basic functionality (e.g., text editing) combined with reliability was most useful. By "basic functionality," we mean that the software provided support for common (and hence very generalizable) functions. The best example of such comprehensive support is Aspects™, which allows people using multiple Macintoshes over a LAN to share screens and simultaneously manipulate document files using text editing, bitmap painting, or object-oriented drawing tools completely consistent with the Macintosh platform's (and interface's) relevant global characteristics. In other words, anyone familiar with the most basic Macintosh interface conventions for these functions already knew the affordances of the Aspects package.

The unexpected "down side" of this transparency was that such readily-usable tools were seen as somewhat simplistic or trivial once the user realized the correspondences between them and ordinary Macintosh capacities. There is a general difficulty in recognizing and appreciating the fundamental motivation for CSCW research -- the collective work team and the collective IT infrastructure are the foci of interest (as opposed to the individual worker and the single IT artifact). We believe this "blindness" carries over into the assessment of groupware. In the case of Aspects™, the value added by synchronous screen sharing did not seem to register on test evaluators, who consistently assayed the package's utility in terms of its utility at their respective workstations. In effect, they eventually downgraded their impressions of Aspects™, apparently on the basis of seeing it as a simple combination of functions found elsewhere (e.g., in SimpleText, MacPaint, and MacDraw). CDTeam, on the other hand, continued to upgrade their impression of Aspects, based on their ability to reliably employ it in a wide variety of situations and over significant lengths of time. In other words, *the addition of collaborative affordances, no matter how elegantly done, was not consistently recognized as a significant achievement.*

The more specialized an application (e.g., the more it relied on a specific data representation or procedure), the less useful we found it. This derived in part from the common inability to import and export file materials. It also derived from the necessity of overcoming a significant "learning curve" before the product's utility was either obtained or appreciated. On the other hand, such specialized packages carried an aura of novelty about them which (at least initially) aroused user interest and motivated the learning process. A good example of this was the Co-Motion™ conference support software, of which we evaluated version 1.5 in autumn 1994. Co-Motion is a collaborative tool for organizing and collating textual comments on a given issue or topic. It provides a reasonably intuitive graphical user interface through which an "essentially unlimited" number of users enter their comments, etc., over an AppleTalk™ or AppleTalk™-compatible network. Remote users may access Co-Motion sessions via Apple Remote Access™ software and a modem. It also offers users the ability to express preferences or rankings on selected points related to the issues under discussion. Finally, summary reports of the session(s) can be printed out.

Any number of Co-Motion users may link into a session resident on a host's machine. Each such user is confronted with a graphical Macintosh window with a tool palette. There are 4 tools:

- A Browser Tool (a pointing hand)
- A Target Tool (denoting Goals or Objectives)
- A Shovel Tool (denoting Problems or Issues to be worked through)
- An Action Tool (denoting Action Items)

Each user clicks on the appropriate tool, then moves his/her cursor to the main window. Clicking the Browser Tool on a given spot in the main window selects an existing item. Clicking one of the other tools on a given spot establishes a new (blank) item of that type. Each such item has a text box allowing up to three short lines of text. Double-clicking on an extant item brings up an Info Window for the given item (or *Idea*). Within the Info Window, the user may:

- Enter text annotations in a scrollable window
- Search through the set of other extant items of the same type as the one selected
- Designate responses or opinions on the pre-packaged questions / issues associated with each type of idea (Polls)

Each of these operations are done under conditions of anonymity -- i.e., no one can tell which user posts which Idea, which notes, etc. A separate Chat Window is provided for posting messages among participants (i.e., notes which are not meant to be inserted into the session record itself). This Chat Window is common to all users, and (unlike some other groupware products) it is not possible for one user to direct a message to another specific user individually. Co-Motion can be used synchronously or asynchronously. This affords flexibility to lay out an issue in a session, then allow others to participate as they are able. We found Co-Motion to be an inexpensive tool best suited for accreting and annotating a problem overview and initial opinions. It would be best suited for policy or decision making conferencing among (e.g.) managers on a local area network.

On the other hand, we found Co-Motion to be a specialized product suited only for issue discussion. Because it does not provide screen or application sharing, it is not suited for synchronous collaborations of the sort supported in Aspects. Because it does not provide an internal capacity for users to direct messages to each other individually, it is not suited for general messaging. It is not suited to applications requiring collaborative action (e.g., group editing), nor is it well-suited for final decision making (e.g., voting). The set of queries to which users could respond in the Polls feature was fixed -- i.e., responses could only be collected to the pre-packaged probe questions. Owing to its highly graphic interface, Co-Motion was initially seen as an attractive medium for discussion of complex issues (e.g., design tradeoffs). As time went on, the relative inflexibility of the package resulted in a reduced estimate of its value. In other words, *the provision of novel collaborative affordances, no matter how effectively done, was not continuously recognized as a significant achievement.*

The examples of Aspects and Co-Motion illustrate a sort of tradeoff in groupware implementation. The dimensions of this tradeoff concern the individual versus the collective, the single workstation versus an entire network, and task specialization versus general functionality. We say "a sort of tradeoff" because it's unclear whether these three dimensions can be sorted out into (e.g.) three separate tradeoff specifications or combined into a single one. It is definitely clear that these dimensions' relative influence may vary depending on situational factors. Both cases illustrate a tendency for initial assessment to concentrate on the way software supports an individual user at his/her own workstation. In the case of Aspects, this leads to underestimating the novelty of the product; in the case of Co-Motion, it leads to overestimating that same novelty. Both cases illustrate a concomitant tendency to initially undervalue or overlook the product's relative scope of application either (1) across diverse synchronous conditions or (2) over time. Our

opinion of the more basic tool (Aspects) rose with sustained usage, while our opinion of the more specialized tool (Co-Motion) correspondingly declined. Too little is yet known of how people collaborate, so it is risky to generally implement the sort of prescriptive normalization imposed by applications such as Co-Motion. For initial or underspecified collaborative tasks, we believe that providing basic tools for generic tasks (e.g., Aspects) is a wiser path to take.

Our opinion is entirely consistent with recent CSCW research. It has been demonstrated that simple tools with general functionality can be remarkably effective at facilitating collaboration (Olson *et al.*, 1992; Hymes & Olson, 1992). By the same token, critical analyses of groupware products' shortcomings have often cited constraints deriving from narrow adherence to a specialized task model (e.g., Whitaker, 1994; Carasik & Grantham, 1988). The dangers of such overspecialization become apparent when a groupware product either fails to give users sufficient leeway to reconcile achievable actions against specifications or to subsequently modify positions in response to collaborators' feedback. The former effect represents a failure to deal with the CSCW-specific issue of *articulation work* -- the translation of formal specifications for goals and work processes into feasible results (Robinson, 1991; Gerson & Star, 1986). The latter represents a failure to deal with the CSCW-specific issue of *mutual influence* -- the ongoing flux in negotiating joint results (Robinson, 1991). Because Aspects provides only a shared medium for open unstructured collaboration, it allows room for both articulation work and mutual influence. Because Co-Motion embodies a particular discursive model and a fixed set of tools, it hinders articulation work (with respect to the discussion itself). Because it forbids retraction of comments, Co-Motion cannot allow for the unfolding of mutual influence.

Desktop Video Conferencing

In October 1994, the CDT Lab was assigned to explore and evaluate the feasibility of installing a desktop video conferencing (DVC) system within Armstrong Laboratory's Human Engineering Division. Our target scenario was the interconnection of approximately 6-8 senior managers through a video conferencing network available to each of them at the desktop. The paradigmatic example of the sort of product expected was a digital video package providing video images on the desktop computer monitor and routing video traffic through the same LAN as the computers' own data traffic. The expected user population was not precisely enumerated at the beginning, but it was eventually specified to be 6 in number, all of whom were Macintosh users. After a massive compilation of relevant literature, vendor documentation, and other information (e.g., from Usenet news groups, World Wide Web), we reviewed the state of the market in this technology area. Our conclusion was that this period (fourth quarter 1994 / first quarter 1995) was a particularly risky time to be investing in DVC technology. The major risks derived from the high cost for decent DVC infrastructure, disparities in DVC product offerings, and the fact that major changes in the DVC area were already in motion.

We found that for microcomputer-accessible DVC capabilities, the costs typically ranged from $1000 per desktop up to around $5000 per desktop. At the bottom end of this scale were hardware-dependent packages utilizing vendor-specific capacities and providing image streams of no more than 10-15 frames per second at best. Such packages were typically limited to only one desktop platform (e.g., Macintosh versus MS-DOS), and they made little or no provision for interoperability with platforms, communications channels, or video standards outside those incorporated in their own product. At the top end of the scale were relatively hardware-independent packages tying desktop workstations into what were effectively dedicated video LANs operating in parallel to the computers' data LANs. These packages permitted full-motion image streams (i.e., 30 frames per second), interoperability across platforms, and compatibility with wide-area communications infrastructures (e.g., ISDN).

In addition to these commercial products, we explored the possibility for using AL / CFH's resident expertise to custom-build a DVC network. This option was ruled out fairly quickly. For

one thing, the cost of equipment equivalent to that provided in the commercial packages was not significantly less. For another thing, we estimated that the cost of contract labor for integrating and installing a DVC system would more than offset any savings obtained from buying generic equipment. Because the initial mandate to CDT Lab invoked computer-based video capacities (as opposed to parallel analog video networks), the apparent expectation was for a solution integrated into a particular class of microcomputers -- thus simultaneously increasing the platform-dependency and decreasing the cost-feasibility of any "homebuilt" solution. Finally, any homebuilt solution would have had to rely on public domain or shareware support software, none of which we judged sufficiently stable to meet our needs.

Our ability to compare products was severely constrained by disparities among the products, vendor specification documents, and evaluators' individual assessments of the specifications we were applying. The most cost-effective microcomputer solutions were typically limited to either MS-DOS or Macintosh platforms. Schemes for patching together two or more such products commonly entailed an expensive intermediary channel (e.g., ISDN) which elevated the composite cost to a level comparable with the more expensive dedicated video LAN solutions. Out of a total field of some 35 DVC products we identified on the market, our choices quickly boiled down to 4 microcomputer-based products and 3 high-end video LAN packages.

It was apparent that costs were dropping for DVC products -- particularly the prices on the digital / analog coder-decoder (*codec*) units necessary to operate local DVC stations over wide-area communications networks. It was also apparent that the higher-end DVC products were a relatively economical solution on a per-workstation basis in cases where the number of workstations increased beyond the 6 we sought to support. We don't mean that the high-end products ever became directly cost-competitive with the low-end products -- only that they became increasingly cost-competitive as the total number of users increased. Phrased another way, our target population of 6 was not sufficiently big enough to warrant the high-end products.

It was also apparent that the fourth quarter of 1994 was a bad time to make long-term decisions on DVC technologies. A number of international standards had either been agreed upon or compiled for consideration during 1994, of which the key ones were:

- ITU-T Recommendation H.320, Narrow-band visual telephone systems and terminal equipment.
- ITU-T Recommendation H.261, Video codec for audiovisual services at p x 64 kbit/s.
- ITU-T Draft Recommendation T.120, Transmission Protocols for Multimedia Data.

These standards provided the first common targets for DVC functionality, and vendors were slowly reacting to the prospect of having to operate in conformance with them. Our evaluations shifted as vendors stated (e.g., in the trade literature) that they were or were not planning for standards conformance. Some vendors -- notably those who claimed no plans for conformance -- were slashing retail prices during the period of our survey. This made their products more attractive in terms of price but potentially less reliable in terms of longevity in service.

We recommend that DVC installation not be attempted until a thorough task analysis is conducted. As an intervention into the communicational network, DVC implementation involves a very significant social aspect. We suggest that a relatively low-cost way for surveying DVC opportunities would be to give workers small video telephone units ($899 each from AT&T; $799 each from MCI as of December 1994) for trial usage. Compared to deploying current DVC technologies, this would be an easy, portable testbed compatible with the existing office telephone infrastructure. Such a modest testbed should be capable of generating data affirming or ruling out options for further, more costly, DVC implementation.

The only consistent utility for DVC identified to date has been in one-on-one informal

conversations. This does not mean DVC should be prescribed for such interactions; DVC installations to date have been plagued by user misanalogies between video-mediated and face-to-face conversation. Experience suggests that DVC is not well-suited for referential (topic-directed) conversation, nor is conversation easily or effectively regulated in DVC channels. Although informal DVC interactions contribute to social bonding, they also permit deception to a greater degree than face-to-face interaction (Fish & Kraut, 1994).

All in all, the evidence supports a view that video is not as important as either audio or shared information (e.g., graphics) in providing effective support for distributed work (Gold, 1992; Tang & Isaacs, 1992). Although interest in DVC technologies is widespread, and market offerings are proliferating, we can find no compelling evidence in the relevant research literature for video adding value to an established communication capability. The latest research results of which we are aware come from a study to be presented at CHI'95 (Denver, May 1995), in which there was a discernible but statistically insignificant performance advantage noted for video-enhanced communications (Olson, 1995). Weak though it is, this would be among the first indications of value added by DVC systems.

Our conclusion is that a "wait and see" attitude is still justified after more than 30 years' commercial marketing of video telephony and DVC products. The DVC market is changing significantly, as evidenced by ongoing progress in standardization, interoperability, and performance. We see the immediate future as a watershed, and currently reasonable market choices are not guaranteed to remain reasonable for 6 months or longer. To guarantee conformance to the emerging standards would require either (1) buying now from low-end vendors and trusting them to migrate to full conformance or (2) buying from high-end vendors already in conformance. We judged the first (low-end) option to be unwise. The latter (high-end) option would be justified only to the extent that (1) a DVC capability is needed immediately; (2) there is a commitment to the product selected as the platform for all prospective expansion of the DVC network; and (3) there is a commitment to global interoperability for the DVC network.

The World Wide Web: Hypertext for Collaboration

The World Wide Web (WWW, W3) project has been officially described as a "wide-area hypermedia information retrieval initiative aiming to give universal access to a large universe of documents" (Hughes, 1994). Originally created as an in-house tool for researchers and collaborators at CERN (i.e., European Particle Physics Laboratory), the WWW has grown and spread to virtually all corners of the globe. Since its inception in March 1989, an estimated 10,000 WWW servers have been placed on-line with hundreds being added daily. The WWW makes large amounts of diverse information (e.g., text, sound, images, and animated video) available to individuals with Internet access and the appropriate browser / interface software. WWW documents are formatted using the Hypertext Mark up Language (HTML) -- a structured annotation syntax derived from the Standard Graphic Markup Language (SGML). HTML extends SGML by providing for hypertext presentation -- i.e., interlinking documents for free-form user navigation. WWW documentation constitutes "multimedia," in that it may contain text, graphic images, animation sequences, and sounds. The ease with which diverse information can be retrieved and transported has placed the WWW in the forefront of Internet technologies. The explosively growing population of WWW server sites and users has placed WWW in the forefront of Internet services.

The WWW functions as a wide-area *client-server architecture*. Hypertext formatted files are stored on a computer that functions as an interactive repository, or *server*. When the server receives a request from a user's browser software (e.g., NCSA Mosaic), or *client*, it responds by transmitting the requested HTML document to the client. Upon receipt, the client's browser software converts the HTML document into a form displayed at the user interface. Conversion and display of some of the diverse data types transmissible in WWW (e.g., sounds, color graphics) are

handled by auxiliary applications (other than the actual browser) which must be resident on the client machine. In this type of architecture, the server "hands off" files as demanded by clients, rather than (e.g.) maintaining an open connection through which the client may browse. This arrangement allows the server to remain maximally available for many users' requests. The tradeoffs are that compared to remote log-on and terminal emulation: (1) the client workstation must bear a more significant burden; (2) the network traffic between client and server will typically be higher; and (3) client response time (from the user's perspective) will typically be slower. A more complete description of the WWW functions and capabilities is beyond the scope of this document.

In an effort to investigate the utility of the WWW for AL / CFH and multimedia / groupware applications, we established a demonstration WWW server on a Macintosh II computer using MacHTTP 2.0 server software. Our development plan was divided into two stages. In Stage 1, we developed multimedia materials exclusively for our Collaborative Design Technology Laboratory to demonstrate the types / structure of information that could be presented by other AL / CFH components. During Stage 1, access to the demonstration materials was limited to Division personnel. The demonstration server was to be evaluated by CDT Lab based on feedback from Division personnel, in preparation for generating guidelines for AL / CFH Division multimedia materials construction.

In Stage 2, we would apply these guidelines to demonstrate how information about all AL / CFH Branches and Laboratories could be presented to "The World." In Stage 2, CDT Lab personnel would coordinate / supervise the HTML formatting and editing of materials supplied by Division, Branch, and Laboratory government personnel. At the completion of Stage 2, all materials would be available for appropriate AL / CFH Division personnel for initial public deployment on an established (i.e., non-experimental) WWW server. Planning is currently underway within AL / CF (the directorate subsuming AL / CFH) for installation and maintenance of a WWW Server.

The Application of WWW Infrastructure to Collaboration. There are a number of efforts underway to explore how the HTML and client / server features of the World Wide Web might be used to support on-line, worldwide collaboration. These are termed *annotation systems*, in that they permit users to add comments to, but not directly modify, documents presented via WWW. A *public annotation system* is one whereby people from all over the Web can publish their comments and annotations to an original document without having to get the document's owner directly involved (Gramlich, 1994). On an experimental basis, NCSA Mosaic version 1.2 (released in 1993) supported a limited-range version of public annotation support called *group annotations*, allowing annotations to documents anywhere on a specific network (e.g., a LAN) shared by members of a particular workgroup. Workgroups would accomplish this by running a dedicated annotation server. Each time someone accesses a document anywhere on the Internet, the annotation server is queried for annotations by any other workgroup members. If such annotations have occurred, hyperlinks to those annotations are interleaved (by the annotation server) into the current document text. At the time of this writing (April 1995), plans were in place for NCSA Mosaic version 2.0 (then in beta version) to eventually incorporate annotation features, but not in its initial release.

Multiple research groups are experimenting with rudimentary collaboration platforms based on HTML annotation. Examples include:

- ComMentor at Stanford University (Röscheisen, Mogensen, & Winograd, 1995)
- CoNote at Cornell University (Davis & Huttenlocher, 1994)
- The Discuss->WWW Gateway at MIT (Dvornik, 1994)
- The WIT (W3 Interactive Talk) structured conferencing system at CERN in Switzerland

- The M.I.T. COMLINK System allowing Federal workers to comment on the Vice President's National Performance Review
- The Mole system at the University of Strathclyde (UK) (Whittington, 1994)
- The W3 Document Annotator at the University of Lausanne (Switzerland) (Schenck, 1994)

Each of these prototypes uses the HTML / WWW infrastructure to implement collaborative messaging and conferencing applications. Even more interesting is the fact that the CERN system WIT is itself an instantiation of the IBIS model previously discussed with respect to design rationale. We believe that these exploratory efforts are the breeding ground for the next generation of groupware developments. By "next generation," we do not mean to imply that these prototypes' functionality necessarily exceeds current groupware products. The innovation in this case lies not in the final functionality delivered to the end user, but in the ubiquity and vendor-independence of the infrastructure upon which they are based. To date, compatibility and interoperability constraints have been the primary banes of groupware installations. These constraints have been aggravated, and in some cases induced, by vendor-specific features. The appearance and dissemination of collaborative infrastructure products based on international standards, using international networks, and employing widely available client software, will likely have a impact on the course of groupware marketing much greater than an innovation in this or that specific functional feature.

Group Interface (GI)

There have been some attempts to address what human-computer interface issues are relevant in group applications (e.g., Brooke, 1993; Hewitt & Gilbert, 1993). Such discussions typically concentrate on the human-computer interface issues pertaining to each of the multiple individual users of a groupware system or those features of group work (e.g., turn-taking) which must be addressed in configuring the software employed via such interfaces. The companion report Whitaker, Longinow and McNeese (in press) summarizes another Collaborative Design Technology Laboratory effort exploring what it would mean to directly interface the technology with entire groups. This work has addressed the human factors aspects of supporting groups with information technology by exploring novel ways of configuring the technology to better meet the needs of teams operating as teams (as opposed to operating as collections of individual end users). We have outlined the relevant background issues and state of the art in group IT support, then analyzed what that state of the art represents. Based on our analysis, we have laid out a research strategy reversing what we consider a "backward" tendency in prior HCI efforts to support complex interactions in co-located teams with technological configurations initially developed for limited bandwidth distributed messaging. By concentrating on concrete engagements between users and IT, we have generated an analytical framework appropriate to the issues critical in defining a *Group Interface (GI)* and applied that framework to delineate the necessary design tradeoffs in constructing a GI artifact. We then describe our initial 1994 prototype of a Group Interface artifact -- the *Unified Interface Surface* or *UIS* -- and discuss the results of our usability evaluation of this UIS prototype.

CONCLUSIONS

During the period 1993 to 1995, the Collaborative Design Technology Laboratory has explored selected issues in Collaborative Design and Collaborative Technology, toward the end goal of innovation in Design Technology. We would like to close by summarizing some of the more general conclusions we have drawn from this experience. These conclusions are "more general" in the sense that they do not derive from only one or another of the research efforts described in this report.

Developing "ecologically valid" frameworks for experimental (or other structured) studies of collaborative design is difficult. However, we feel that solid data from real-world design activities and practicing design experts can be collected and collated in a sufficiently structured fashion to provide a foundation for such work. Three of our projects -- the TRACE experimental paradigm, the ASC Collaboration Study, and the AutoMate paradigm -- drew upon a single body of data collected from design professionals concerning an automobile navigation system task. The multiple payoffs from this single effort have justified the initially large investment in time and effort. We believe that this investment will be further justified as the results are fed forward into one or more series of design studies. We believe that our strategy of feeding detailed empirical data on design experiences into TRACE and AutoMate, then making those paradigms (or sessions based on them) available for inspection and feedback by design professionals (e.g., the debriefings after each TRACE session) allows us to expedite ongoing collection and validation of ecologically valid data on design collaboration.

Collecting observational data on real-world design activities is time-consuming, resource-intensive work. On the other hand, there is no other method guaranteed to provide so detailed a trace of actual design collaborations. Barring the utilization of comprehensive automatic workplace monitoring, there is no way to avoid dedicating hundreds or thousands of person-hours to such an effort. Even when using electronic monitoring (e.g., videotaping), transcription of the raw data into analyzable / archivable form can entail an effort of similar magnitude to the on-site data collection. The scale of investment necessary to conduct an observational study should motivate researchers to comprehensively plan their tactics and budget their resources. This is made more critical by the fact that observational studies are essentially "all or nothing" in nature -- once begun, they must be carried through to completion. Our experience affirms the utility of observational approaches in studying design collaboration. Recent advocacy of such methods (particularly in academic circles) is well-justified, but solid "how-to" information and / or experienced observational researchers are less readily obtained. We are concerned that for large-scale, mission critical design exercises (as are typical in USAF design acquisition), researchers (or others -- e.g., quality managers) contemplating observational data collection should carefully assess the costs and requirements of doing such work effectively.

Collaborative technologies are (as unit investments) more expensive than earlier types of IT products. We do not mean to imply that groupware supporting X workers necessarily costs more than (e.g.) individual productivity packages for each of those X workers. We only mean to emphasize that the *unit* investment entailed in a single groupware innovation necessarily includes the cost of innovation covering all X of those workers *at once*. For a LAN-based system, there must be sufficient investment to achieve a parity of equipment among collaborators in addition to the necessary infrastructure (e.g., LAN cables, servers, etc.). Compatibility and interoperability issues require more than simple lip service, because everyone must be able to work together. The high scale of basic investment is matched by a correspondingly high level of enterprise commitment required to get everything "up and running" and everyone "on board." These factors result in groupware being a "high stakes" investment whose risks, like its advertised payoffs, are of a strategic scale.

Collaboration is not simply a matter of installing collaborative technology. Recall our earlier

contrast between two models of productive collaboration: that of Ford (linear production via individual throughput on subtasks) versus Volvo / Kalmar (flexible production via team synergy throughout the whole task). Concurrent engineering, the USAF's IPD, and other nascent innovations in design methodology represent a shift from the Ford to the Kalmar style. This is not something that can be implemented through simple invocation of change. Today's design professionals are accustomed to linear, compartmentalized design paths along which they feed forward their results by "tossing it over the wall" to the next person. Changing habits and attitudes from the "Ford era" will take time, and attention must be paid to the social / behavioral impacts of innovations entailing collaborative practices.

Collaborative technologies cannot reasonably be evaluated using the same techniques or metrics as prior IT innovations. Assessing group productivity or collaboration payoff is not as straightforward as measuring (e.g.) individual throughput. Combined with the necessarily large costs and/or risks for groupware implementation, this makes it difficult for management and planners to prospectively justify migration to collaborative IT solutions. Nonetheless, there are some conventionally-framed results (in terms of *Return on Investment* or *ROI*) which can be cited. In a 1994 survey of 65 Lotus Notes™ users, International Data Corporation found an average 3-year ROI of 179% (of investment) and an average investment recoupment period on the order of 2.4 years (Simpson, 1994). The average initial investment for each subject organization's enterprise-wide Notes implementation was $240,000. Because Notes is more an "infrastructure" than an "application" product, we believe this scale of payoff is probably higher and more clearly delineated than would be the case for more specialized groupware acquisitions (e.g., group decision support systems). As such, we see no reason to predict that assessing groupware payoffs will become easier in the foreseeable future.

The aforementioned joint levels of investment and commitment for groupware are necessitated by the fact that IT-supported collaboration entails conformity and compatibility. If one considers groupware at the scale of global (as opposed to enterprise-specific) conformity and compatibility, it becomes apparent that one or another user organization is not likely to exert sufficient leverage to steer marketplace developments. It will become increasingly difficult to justify in-house products by comparison with commercial offerings. This effect will be compounded by the integration of internationally-recognized standards into the requirements specifications for all products and the activities they support. This is not necessarily negative -- the arrival of international standards (e.g., the H.320 suite) and integrated tools (e.g., Apple MovieTalk™) for desktop video conferencing will certainly result in decreased unit costs for DVC applications. On the other hand, this is not to say that the future marketplace will always keep its eyes solely on the future. The "irresistible force" of explosive growth for infrastructure products such as the World Wide Web may well coalesce into "immovable objects" with which subsequent innovators must interoperate, regardless of any appearance of better options in the mean time. As a result, we see no reason for considering in-house development of groupware "from the ground up" except for research, highly specialized, or mission-critical applications.

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APPENDIX A

Pointers to Relevant Resources in the World Wide Web (WWW)

The following are selected addresses for relevant information resources on the World Wide Web (WWW). The items beginning with "http://..." are *Uniform Resource Locators (URLs)* -- the standard addressing convention for WWW.

I. INFORMATION ABOUT THE WORLD WIDE WEB

A. World Wide Web Development:

1. Virtual Library/Cyberweb: WWW Development

   http://www.charm.net/~web/Vlib.html

2. Stanford's Yahoo Server: Computers/WWW

   http://akebono.stanford.edu/yahoo/Computers/World_Wide_Web

3. CERN (World Wide Web Originators)

   http://info.cern.ch

4. Massachusetts Institute of Technology (WWW Host US Sponsor)

   http://web.mit.edu

5. INRIA (WWW Host European Sponsor)

   http://www.inria.fr

B. Search Engines (i.e., tools for searching WebSpace)

1. Web Crawler

   http://webcrawler.cs.washington.edu/WebCrawler/Home.html

2. WWW Worm

   http://www.cs.colorado.edu/home/mcbryan/WWWW.html

3. Lycos

   http://lycos.cs.cmu.edu

C. WWW Catalogs (some of which provided automated search capabilities)

1. CERN's Virtual Library

   http://info.cern.ch/hypertext/DataSources/bySubject/Overview.html

2. Whole Internet Catalog at O'Reilly and Associates

   http://nearnet.gnn.com/wic/newrescat.toc.html

3. CERN

   http://cuiwww.unige.ch

4. Stanford's Yahoo

   http://akebono.stanford.edu/yahoo

5. EINet Galaxy

   http://www.einet.net

6. University of Michigan Clearinghouse

   http://www.lib.umich.edu/chhome.html

7. Planet Earth

   http://teal.nosc.mil/info.html "Planet Earth"

8. Yanoff's Connections

   http://www.uwm.edu/Mirror/inet.services.html

II. CSCW, HUMAN FACTORS AND RELATED WEB SERVERS

A. Human-Computer Interaction

1. Index of HCI Related Information

   http://www.twi.tudelft.nl/Local/HCI/HCI-Index.html

2. HCI section of the WWW Virtual Library

http://www.cs.bgsu.edu/HCI/

3. HCI Resources

   http://www.ida.liu.se/labs/aslab/groups/um/hci

B. Computer Supported Cooperative Work

1. CSCW Directory

   http://www.demon.co.uk/jrac/cscwdir.html

2. The Unofficial Yellow Pages for CSCW

   http://www.tft.tele.no/cscw/

3. Web-Searchable Bibliography on CSCW

   http://www11.informatik.tu-muenchen.de/cscw/cscw-biblio.html

4. Collaborative Software Resource Clearinghouse

   http://www.ics.hawaii.edu/~jl/CSRC.html

C. Desktop Video Conferencing (DVC)

1. Introduction to DVC

   http://fiddle.ee.vt.edu/succeed/videoconf.html

2. Survey of DVC products

   http://www2.ncsu.edu/eos/service/ece/project/succeed_info/dtvc_survey/prod
   ucts.html

3. The H.320 video telephony standards documentation (from ITU)

   http://www.itu.ch/itudoc/metadocs/23397.html (direct download of H.320)

   gopher://info.itu.ch/11/.1/Stds-Pub-etc (Gopher access to all ITU standards)

D. Computer-Mediated Communication

1. Computer-Mediated Communication Studies Center

   http://www.rpi.edu/~decemj/cmc/center.html

2. The Internet and Computer-Mediated Communication

   ftp://ftp.rpi.edu/pub/communications/internet-cmc.html

E. Other Relevant Resources

1. American Communication Association

   http://cavern.uark.edu/comminfo/www/ACA.html

2. Information Science World

   http://www.cox.smu.edu/mis/iswnet/home.html

3. National Coordination Office / High Performance Computing and Communications

   http://www.hpcc.gov

4. Misc.creativity home page (includes some material on group facilitation)

   http://www.unidata.com/~ucc01/creative.htm

APPENDIX B

Published Periodicals of Relevance to CSCW

Computer Supported Cooperative Work: An International Journal

Collaborative Computing

ACM SIGCHI Bulletin

ACM SIGOIS Bulletin

ACM Transactions on Computer-Human Interaction

ACM Transactions on Office Information Systems

Communications of the ACM

Decision Systems

Group Decision and Negotiation

Human Computer Interaction

International Journal of Man-Machine Studies

International Journal on Intelligent and Cooperative Information Systems

Management Communication Quarterly

MIS Quarterly

Office: Technology and People

Organizational Science

APPENDIX C

Usenet Newsgroups of Relevance to CSCW and other Topics Discussed in this Technical Report

bit.listserv.quality	(quality management, TQM, etc.)
bit.listserv.qualrs-l	(qualitative research, observational studies)
comp.cog-eng	(cognitive engineering)
comp.dcom.*	(hierarchy of groups about data communications)
comp.groupware	(CSCW and groupware)
comp.groupware.lotus-notes.misc	(Lotus Notes)
comp.human-factors	(human factors and HCI)
comp.infosystems.www.*	(hierarchy of groups about the World Wide Web -- WWW)
comp.multimedia	(multimedia)
misc.business.facilitators	(meeting / group process facilitation)
rec.video.desktop	(desktop video production and some DVC issues)
sci.anthropology	(occasional news and information on ethnography)
sci.cognitive	(cognitive studies)
sci.med.telemedicine	(distributed medical applications)

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